DESCHUTES RIVER

SPAWNING GRAVEL STUDY

VOLUME I

FINAL REPORT

by

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF TABLES

LIST OF TABLES (continued)

LIST OF TABLES (continued)

LIST OF TABLES (continued)

LIST OF APPENDICES

LIST OF APPENDICES (Continued)

ABSTRACT

The Deschutes River Spawning Gravel Study was conducted under the auspices of the Bonneville Power Administration, as one of the measures in the Northwest Power Planning Council's Fish and Wildlife Program. This program measure is in response to concern that controlled flows and restricted gravel movement below the Pelton/Round Butte Hydroelectric Complex may have degraded spawning habitat for wild fall chinook salmon and summer steelhead trout in the 100.1 miles of the Deschutes River below PGE dams. Project objectives were to: (1) collect data on the present quantity, quality and distribution of spawning gravel in the river; (2) compare these data to existing baseline data collected by the Oregon State Game Commission at the time the hydrocomplex was completed in the mid 1960's; (3) to quantitatively assess the extent and magnitude of changes: (4) to create a new qualitative and quantitative baseline on spawning habitat conditions in the river; and (5) to recommend measures for rehabilitating or enhancing spawning habitat in the Deschutes.

During the study, spawning habitat in the Deschutes River was inventoried, gravel permeability and composition were sampled at selected gravel bars, historical flow records for the Deschutes were analyzed, salmon and trout utilization of spawning habitat was examined, and potential methods of enhancing spawning habitat in the river were explored. The results of these efforts are reported here. Some changes in river conditions since the mid-1960% were identified, including a reduction in spawning habitat immediately downstream from the hydroelectric complex. The 1964 flood was identified as a factor which profoundly affected spawning habitat in the river, and which greatly complicated efforts to identify recent changes which could be attributed to the hydrocomplex. A baseline on present gravel quality at both chinook and steelhead spawning areas in the river was established using a freeze-core methodology. Recommendations are made for enhancing spawning habitat in the Deschutes River, if it is independently determined that spawning habitat is presently limiting populations of summer steelhead or fall chinook in the river.

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We would like to thank Dale Johnson, BPA's Project Manager, for his dedication, patience, understanding and valuable comments on the final report. Tom Berggren, also of the BPA, provided valuable assistance with data management and reduction problems.

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INTRODUCTION

Native stocks of chinook salmon (*Oncorhynchus tschawytscha*) and summer steelhead trout (*Salmo gairdneri*) have declined to very low levels throughout much of the Columbia River basin. The continued existence of many of these stocks is uncertain and is dependent upon man's careful stewardship of the rivers and streams which produce them. One aspect of this stewardship is the identification and solution of critical problems facing anadromous fish populations within the system.

The Deschutes River in north-central Oregon supports valuable wild stocks of fall chinook salmon and summer steelhead. These stocks in turn provide fishing opportunities for sport, commercial and Indian subsistance fishers.

Anadromous fish were once found throughout much of the

Deschutes drainage (Len Mathisen, ODFN-retired, Bend, Oregon, pers. comm.). However, man's activities in theDeschutes Basin since white settlers first arrived in the 1860's have led to a progressive reduction in the availability of productive habitat for anadromous fish. Stream dewatering for irrigation, poor land use practices, major floods and dams have all played a substantial role in this reduction of habitat.

Today, natural production of anadromous fish within the drainage is restricted to the mainstem Deschutes below the Pelton/Round butte Hydroelectric complex (RM 100.1) and a few lower river tributaries.

Like most large rivers in the Columbia Basin, the Deschutes has been dammed for hydroelectric power generation. Portland General Electric Company (PGE) constructed a three dam hydroelectric project on the mainstem above river mile 100.1 in the 1950% and 60's. The three dams are collectively referred to as the Pelton-Round Butte hydro complex. Pelton Dam (RM 102.9) and its reregulating dam downstream (RM 100.1) were completed in 1964, essentially ending natural production of anadromous salmon and steelhead in the upper Deschutes drainage. Round Butte Dam

(RM 110.4) completed the hydro complex in 1964. Although partially successful efforts were made to pass adult fish around the three dams via a three mile long fish ladder and a tramway system, no effective means of getting juvenile salmon and steelhead to migrate downstream through Round Butte Reservoir was ever developed. Since 1973, efforts to compensate for lost production of wild fish in the upper basin have been centered around a mitigation hatchery financed at Round Butte by PGE and operated by the ODFW.

PGE currently operates its hydro complex within certain guidelines established by the Federal Power Commission and abides by other agreements made with the Oregon Department of Fish and Wildlife (ODFW). Minimum flows released below Pelton Reregulating Dam should be greater than 3,500 cfs from March through June and greater than 3,000 cfs during the rest of the year unless inflow to the PGE complex also falls below these levels. Although the pattern of water storage and discharge at the PGE complex varies between storm events, seasons, and years, the general effect of the dams is to increase average winter flows and decrease average spring flows downstream.

Given the value of the wild salmon and steelhead stocks in the Deschutes, biologists with the Oregon State Game Commission (OSGC), voiced serious concern in the 1960's that altered flow regimes below the hydrocomplex would lead to degradation of spawning habitat in the lower mainstem Deschutes. They noted that good spawning gravel was relatively scarce with much of the gravel too compacted for fish use. They also noted that reductions in the quantity or quality of suitable spawning gravels in the river might cause fish populations to decline. OSGC biologists speculated that controlled flows below the hydrocomplex would lead to sedimentation and compaction of additional gravel bars that were heavily used by spawning fish, because these gravels would no longer be mobilized by peak flows.

In order to develop operating criteria for the PGE hydrocomplex, the OSGC conducted the Lower Deschutes Flow Study. This baseline study examined the quality, quantity, distribution and utilization of spawning gravel for salmon and trout in the lower Deschutes from 1961 through 1966 (Aney et al., 1967). Based on the results of their study, the OSGC recommended minimum river discharges below the PGE complex of 4,800 cfs during the major trout spawning and incubation period, March 15 through July 15, a minimum discharge of 4,500 cfs during the major salmon spawning and incubation period, September 15 through February 15, and a minimum discharge of 4,200 cfs at all other times (Aney et al., 1967). It was further noted that if minimum legal flows proposed by the Federal Power Commission were allowed to stand, which they have, there would be reductions in available spawning area of 27 percent in the spring and 39 percent in the fall whenever these flows were matched. The OSGC also tentatively proposed that a flushing flow of at least 8500 cfs be released from the project each year for a period of at least 36 hours to cleanse gravels of accumulated fine sediments (Aney et al., 1967). None of the OSGC recommendations were adopted by the Federal Power Commission as operating criteria for the hydrocomplex.

The concerns raised by the OSGC in the 1960's were well founded. Hydroelectric dams often effect changes in the quantity and quality of downstream spawning habitat through changes in gravel recruitment patterns, channel armoring, sedimentation caused by reduced tractive forces ("scour flows”), alterations in the hydraulic geometry of stream channels due to modified flow regimes, riparian encroachment, and changes in interflow (percolation) characteristics (Leopold and Mattock, 1953; Bustis and

Hillen 1954; Chambers et al., 1955; Brett, 1957; houston, 1958; Curtis, 1959; Delile and Eliason, 1961; Phillips, 1969; Burns, 1970; Coots, 1972; California Department Fish & Game, 1974; Hamilton and Buell, 1976; E'essler, 1977; Buell, 1979; California Department of Water Resources, 1981, 1982: Reiser et al. 1985).

Recent shifts in the percentage distribution of fall chinook spawning activity in the lower Deschutes suggested that spawning habitat in the river has been degraded by the PGE hydro complex. It was thought that by restricting gravel movement and regulating lower river flows the dams had caused a shift in the spawning distribution of fall chinook salmon that reflected a decline in the quality and quantity of spawning gravel.

The ODFW subsequently recommended a follow-up study to document the extent and severity of any spawning habitat degradation. The primary objective of the study was to identify and rectify existing spawning habitat problems. The recommendation was adopted as a measure in the Northwest Power Planning Council's (NWPPC) draft Fish & Wildlife Program, and a study funded by the Bonneville Power Administration (BPA). This report presents the results of that study.

The major goals of this study were to define current spawning habitat conditions in the lower 100 miles of the Deschutes River below Pelton Reregulation Dam, compare conditions to those documented during the OSGC study in the mid-1960's, and recommend realistic options for improving spawning habitat in the river. Five study objectives were identified as being essential to meeting these goals. These included:

1. Examine the quantity and distribution of spawning gravel for fall chinook and summer steelhead and compare findings with those of the OSGC (1967) Study.

2. Examine and campare existing gravel permeabilities with those measured during the OSC study.

3. Define new baseline conditions of gravel quality in different river reaches using the best methods available (a) to compare present gravel quality among different sections of the river and (b) as a basis for evaluating the effectiveness of any future spawning gravel improvement measures.

4. Use data from Study Objective 3 to determine how well the distribution of fish spawning activity in the Deschutes River reflects differences in gravel quality between different sections of the river.

5. Summarize findings and formulate recommendations for improving spawning habitat for wild fall chinook salmon and summer steelhead trout in the Deschutes River.

Spawning habitat damage caused by altered flow regimes below the Pelton/Hound butte hydrocomplex was to be identified during this study. As the study proceeded and understanding of the river increased, it became apparent that the effect of the 1964 flood on the Deschutes greatly complicates any analysis of hydrocomplex impacts on the river. This flood was the largest flood recorded on the Deschutes and had a profound effect upon the river (Aney _et al_., 1967). Although the OSGC collected data both before and after the 1964 flood, in some cases the baseline informaticn and analyses did not clearly quantify the effect that the flood had on spawning habitat in the river. For this reason a great deal of emphasis in this study was placed upon carefully examining records of the

1964 flood event, reanalyzing data collected in the 60's by the OSGC, and determining to the extent possible the effects that the flood had on spawning gravel in the Deschutes.

Round Butte Reservoir was filled for the first time during the 1964 flood, containing the flood "spike" or peak, and dramatically affecting downriver flows and gravel movement. In fact, one of the greatest effects the PGE dams have had on the quantity, quality and distribution of spawning gravel in the Deschutes probably resulted from water storage during a few days in December 1964, thereby preventing the removal or destruction of spawning habitat immediately below the hydro complex.

STUDY AREA

The Deschutes River basin is located in north-central Oregon. The basin drains an area of 10,400 square miles (Oregon State Water Resources Board, 1961).

The study area encompasses that part of the Deschutes River below the Pelton/Round Butte hydrocomplex located at River Mile (RM) 100.1. There are 760 miles of perennial and 1440 miles of intermittent streams draining the 2,70U square miles of the lower Deschutes basin. Major tributaries in the lower basin include the Warm Springs and White Rivers, as well as Shitike, Trout, Eagle, Nena, Bakeoven and Buckhollow Creeks.

The climate of the Deschutes basin is continental. Average annual precipitation in the Deschutes Valley ranges from 9 to 14 inches, with only 25 percent occurring between 1 May and 30 September (Aney et al. 1967). The tributaries to the Lower Deschutes are subject to sudden flow increases caused by either heavy precipitation or rain-on-snow events. The resultant "flash floods" cause severe watershed and stream channel erosion. These floods are characterized by extreme water turbidity and heavy sediment loads which subsequently affect the mainstem Deschutes.

Deschutes River discharge has been extremely stable historically. Average annual flows typically range from 4,000-6,000 cfs at RM 100 and 5,000-10,000 cfs at the mouth. Seasonal variations in streamflow of a single order of magnitude have been rare. The maximum flow recorded at RM 100 was 15,200 cfs; and 73,900 cfs was the maximum daily flow recorded at the mouth.

The major geologic component of the Lower Deschutes basin from the river mouth to RM 60 is Columbia River basalts. From RM 60 to 100 the underlying geologic components are composed of John Day and Clarno formations, chiefly sedimentary and consolidated sedimentary and volcanic rock.

The parent material has had an influence on the character of the lower Deschutes, which flows through a narrow, winding canyon 700 to 2,200 feet deep. The average stream gradient is 0.23%. Major features include Sherars Falls, a vertical drop of 15 feet and White Horse Rapids with a drop of 35 feet in one mile.

The Lower Deschutes River was divided into four study sections based on those of the OSGC Study (Figure 1) (Aney et al., 1967). Section I extends 3.3 miles from the Pelton Reregulation Dam downstream to Shitike Creek (RM 96.8). This section averages approximately 231 feet in width and is characterized by relatively stable flows and silt-free water. Pelton Reregulation Dam has a very pronounced effect on river discharge patterns in this section.

Study Section II averages 202 feet in width, extending 13.0 miles from Shitike Creek to the mouth of the Warm Springs River (RM 83.8). This section is influenced by several tributaries which modify the mainstem flow with their occasional high discharges and sediment loads. For example, Trout Creek (RM 87.2) has been observed to discharge highly turbid flows of 25 cfs, discoloring over 5000 cfs of Deschutes mainstem discharge', and noticeably reducing water clarity all the way downstream to the mouth.

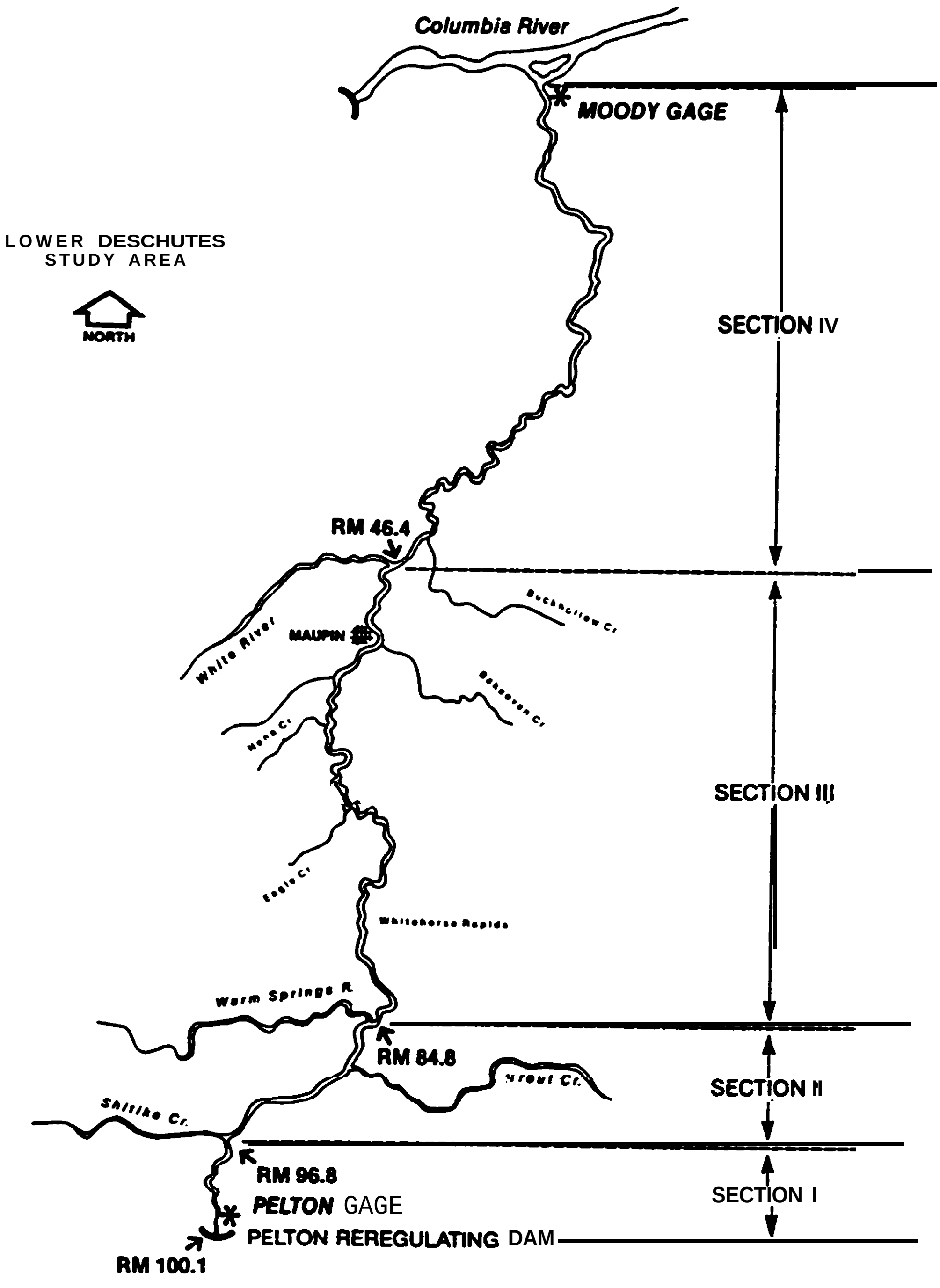


Figure 1. The Lower Deschutes Study Area and its four Study Sections.

Study Section III averages 204 feet in width and is 37.2 miles long, extending from the Warm Springs River to the mouth of White River (RM 46.6). Streamflow in this reach is strongly influenced by the normally stable and clear discharge of the Warm Springs River. Like Study Section II, this Study Section is affected by discharge from a number of tributaries and relatively infrequent flash floods carrying large volumes of silt-laden water. Tributary streams exerting particular influence on Study Section III are Bakeoven, Nena and Wapinitia Creeks.

White River has a major effect on Study Section IV, which extends 46.4 miles from its mouth to the Columbia River. This section averages 275 feet in width. White River (a river of glacial origin) has wide discharge variability and will, at times, carry heavy loads of glacial sand and silt. Flash flooding from Buck Hollow Creek also has an effect on this Study Section.

Salmonids of major importance in the lower Deschutes River include chinook salmon, steelhead trout and resident rainbow trout (*Salmo gairdneri*), commonly known as "redsides". The lower Deschutes supports a famous and highly productive sport fishery, primarily for resident rainbow and steelhead trout.

Fall chinook salmon enter the Deschutes between August and October. Small runs of spring chinook salmon enter mainly during April and May. Most chinook salmon spawn between late September and mid-November. Fry emerge from the first of January to late March (Jim Newton, ODFW, The Dalles, OR, pers. comm.). Most juveniles migrate to the ocean in their first and second years, maturing in the ocean and returning to spawn four or five years after the parent run (Bob Lindsay, ODFW, Madras, OR, pers. comm.).

The major portion of the steelhead run enters the river from late June through September, spawning from March to June the following year. Fry emergence occurs between late May and July. Juveniles remain in the Deschutes one to two years before migrating to the ocean to mature. Most return to spawn during the third or fourth spring following emergence. Deschutes steelhead range from 3 to 15 pounds in weight, averaging about 6.0 pounds (King, 1965).

Resident rainbow trout reach up to 20 inches in length, and are characteristically deep-bodied. The majority spawn in the mainstem Deschutes between mid-April and late June and in the tributaries during March and early April. Little is known about the relationships between these mainstem resident fish and migrant steelhead. Studies recently conducted by the ODFW indicate that there is some genetic distinction between the two strains (K. Schroeder, ODFW, Maupin, OR, pers. comm.).

Figure 2 shows the major spawning and egg incubation periods for fall chinook salmon, steelhead and resident rainbow trout in the lower Deschutes River. Gravel in the river is utilized for salmonid spawning or egg incubation nearly year round.

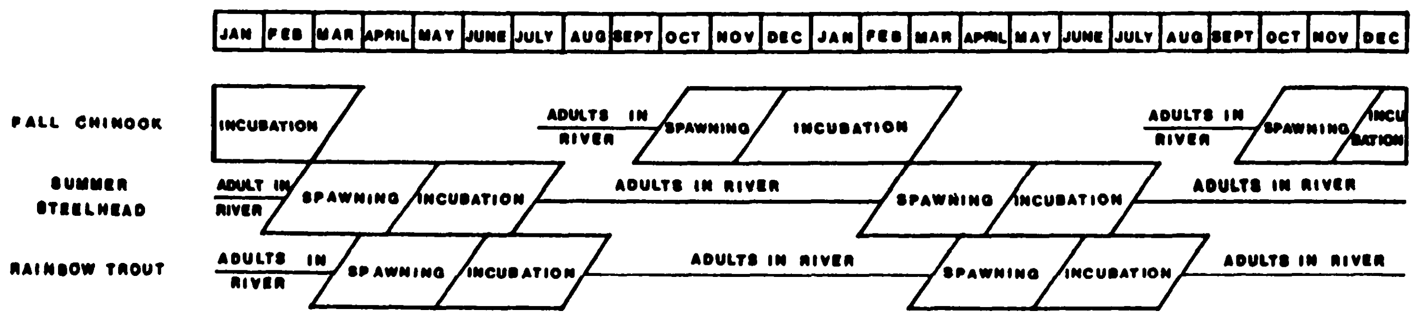


Figure 2. Major spawning and incubation periods for fall chinook salmon, summer steelhead, and resident rainbow trout in the lower Deschutes River, Oregon (Source: Steve Williams, ODFW, The Dalles, Oregon).

METHODS

GRAVEL BAR INVENTORY

The present quantity and distribution of gravel suitable for salmon and trout spawning in the lower Deschutes were estimated by combining air photo interpretation with an extensive gravel bar inventory and communication with ODFW biologists familiar with the river. First, infrared air photos (1:2000 scale) providing coverage of the river below Pelton Reregulating Dam (RM 100.1) were examined and the location of apparent gravel deposits marked on photo overlays (Appendix I). Locations of additional gravel bars that had been either identified during the Lower Deschutes Flow Study or seen in recent years by ODFW biologists were also indicated on the overlays.

It was anticipated that an intensive examination of a small subset of the gravel bars within each study section could be combined with the photo interpretations to accurately estimate the quantity and distribution of suitable spawning gravel within the entire study area. However, the often armored, compacted or embedded character of much of the gravel in the Deschutes prevented reliable predictions of gravel suitability based upon air photo interpretation.

At the recommendation of ODFW biologists, an extensive spawning gravel inventory of the entire lower Deschutes River was conducted. This inventory utilized techniques employed during the OSGC baseline study. Major advantages to this approach were that it provided complete documentation of gravel conditions in the river and that it allowed maximum flexibility in comparing data on present conditions to those reported by the OSGC.

Plans to systematically measure water depth, water velocity, and substrate composition along transects established at a number of gravel bars within each study section were abandoned when it became evident that the measurements obtained would not help meet the goals of this study. More specifically, the transect work was not done because:

0 Transect work was not needed to develop results which could be compared to those of the OSGC. Although OSGC biologists measured water depths and velocities along transects established in spawning areas, the measurements were used solely to predict the effects of fluctuations in river flows on available spawning habitat in in each of the four study sections. The OSGC did not use its transect data to estimate total spawning area.

0 Direct comparisons to the OSGC transect data were not possible. An effort was made to take one-time depth and substrate measurements along habitat transects established in the 1960's when the OSGC mapped some of their sampling stations. This might have allowed some analysis of recent changes in gravel bar morphology. The value of this effort was dependent upon observing habitat transects at flows similar to those present when they were originally established. Few of the transect benchmarks could be located, and proper flows were not encountered during this study at those transect sites which were found.

- Computer-compatible transect measurements that were to be taken woula have required considerable follow-up work in order to model relationships between streamflow and available habitat. The ODE'W did not anticipate that it would conduct this follow-up work and therefore saw little benefit in having the initial transect work done.

Spawning gravel areas for salmon and trout in the lower Deschutes River were inventoried from a motorized drift boat in September and October 1983, and from May through September in 1484. All areas of suitable spawning gravel which could be located, including those roughly delineated through air photo interpretation, were sketched on air photo overlays. Each bar outline was then assigned a code number and keyed to a field data sheet upon which specific information on the bar was recorded (see Appendix VI). Information recorded for each bar included the date surveyed, river mile, position in the channel, mean length and width when measurements were possible, apparent size composition of surface gravels, apparent quality of surface gravels, percentage of gravel that salmon and trout could use under prevailing conditions, and factors potentially limiting the ability of salmon or trout to utilize the gravel deposit for spawning.

In Fall 1983, deposits of suitable spawning gravel in the wetted channel of the lower Deschutes were measured and delineated on air photo overlays. In the spring and summer of 1984, additional deposits of suitable spawning gravel, which were unwetted or thought unsuitable in 1983 were measured and delineated on overlays. These follow-up measurements were necessary to fully quantify areas of gravel which could be utilized by trout and to account for changes in what field crews considered usable spawning gravel based upon observations of fish spawning activity in the river. In addition, follow-up examinations of some bars, particularly along the river margins and in side channels, showed that areas overgrown with aquatic vegetation in the fall were sometimes free of vegetation during the winter, spring and early summer, and hence usable for steelhead and resident trout spawning.

based upon observations made in the field, the proportion of each size class of spawning area gravel which could be used by spawning trout or fall chinook was estimated based upon prevailing conditions of flow and vegetation overgrowth.

The surface camposition of spawning gravels located during the study was categorized by estimating the percentage of bar surface over which each of the following six gravel classes predominated :

Gravel Class	Size
0	under l/4" diameter (not used for spawning.)
I	l/4 to 1" diameter (used by trout for spawning)
II	1 to 3" diameter (used by trout for spawning)
III	3 to 6" diameter (used primarily by fall chinook for spawning)
IV	6 to 10" diameter (used by some fall chinook for spawning)
V	over 10" diameter (not used for spawning)

This gravel classification scheme was used during the OSGC baseline study. In cases where water depth prevented physical inspection of gravels in known fall chinook spawning areas, the composition was assumed to be 50 percent Class III gravel and 50 percent Class IV gravel. This composition was assumed because it was typical for shallower gravel bars used by spawning fall chinook.

Field data on some fall chinook spawning areas located in deep water were adjusted as a result of observations made during helicopter flights over the river in October 1983 and November 1984. Spawning areas in deep water were often more effectively surveyed from the air than they had been during the drift boat inventory. Based on these helicopter observations, bar outlines sketched during the ground-level inventory were shifted on photo overlays to account for areas in which fall chinook redds could be seen from the air. In a few cases entirely new spawning areas for fall chinook were identified and recorded.

Surface gravel quality at each bar was classified subjectively based upon the likelihood of successful fish spawning and reasonable egg survival. Gravel quality was generally estimated after close examination of a bar and the performance of numerous "kick tests" to check for gravel looseness. These tests involved repeated kicks of the gravel surface with a boot toe.

The classification scheme used to describe the quality of surface gravels in each bar was:

<u>Gravel Quality</u>	<u>Description</u>

Excellent	No apparent limitations to gravel quality; very high egg survival expected.
Good	Few limitations to gravel quality; good egg survival expected.
Fair	Gravel marginally suitable for spawning; moderate egg survival expected.
Poor	Fish use highly unlikely: very low egg survival.

The quality of spawning gravel in water too deep for close inspection was estimated by considering the intensity of known spawner use and the quality of adjacent gravel deposits in shallow water. Gravel classified as excellent, good, or fair in quality was considered suitable for spawning by salmon or trout; bars with poor gravel quality were not considered suitable. This assignment of suitability to specific quality classes of gravel was made in consultation with the ODFW after completion of the gravel inventory.

Bar outlines mapped on photo overlays were reviewed and finalized in consultation with ODFW biologists. Surface areas of gravel bars for which dimensions could not be measured in the field (usually because of excessive water depth) were then determined from planimeter measurements of bar outlines. The gravel inventory data were then coded, keypunched onto permanent IBM tape, and transferred to BPA's Computer Center in Vancouver, Washington for analysis.

Data recorded for each gravel bar examined in 1983 or 1984 were used to calculate the surface area of spawning gravel for each gravel quality class and size class. The formula used was:

$$N_{jki} = A_i \times Pki \times Ski$$

where:

N_{jki} = the surface area of spawning gravel of quality class "j" and size class "k" at gravel bar "i"

$A_i =$ total surface area of gravel bar "i"

P_{ki} = decimal percent of gravel bar surface that was size class "k" at gravel bar "i"

S_{ki} = decimal percent of class "k" gravel considered suitable for use by spawning salmon or trout at gravel bar "i"

The surface areas of suitable spawning gravel within specific reaches of the river were then estimated by summing the surface areas of all suitable gravel deposits within each specific reach of interest.

Reliable comparisons between the present quantity and distribution of spawning gravel in the Deschutes and the information reported by Aney et al. (1967) were difficult. Part of this difficulty arose from initial misinterpretations of the rationales and methods used by the OSGC when they quantified spawning gravel. These misinterpretations resulted from a lack of available documentation on work done by the OSGC and the long period of time which has elapsed since the original baseline study. In addition, some of the raw data collected by the

OSGC on the distribution and abundance of spawning gravel in the Deschutes have been lost since their study was completed almost twenty years ago.

Given these problems, an attempt was made to understand the changes in gravel quantity and distribution which have taken place on the Deschutes since the 1960's. This effort involved a compilation of bar inventory data that was recovered from inactive files at ODFW offices in Portland, The Dalles, Bend and La Grande. The results of this compilation are presented and discussed later in this report, as are difficulties encountered when comparing our results to historical data collected by the OSGC on spawning habitat in the Deschutes.

GRAVEL QUALITY

Spawning gravel quality in the lower Deschutes River was examined quantitatively by sampling gravel permeability and gravel composition at representative spawning areas in each of the four study sections. Photos taken of each spawning area sampled during the study are provided in Appendix II.

Gravel permeability was determined using a standpipe methodology developed by Terhune (1958) and used by the OSGC during its baseline study. Permeability sampling sites were matched with those of the OSGC to the greatest extent possible. In this manner, major gravel quality changes which have occurred since the baseline study should have become evident upon examination of the permeability data collected.

The gravel composition of selected spawning areas was sampled using the freeze-core methodology developed by Walkotten (1976) and refined by Everest et al.(1980). This technique allows gravel samples to be stratified by depth, a capability which can prove helpful in identifying quality changes or problems (Everest et al. 1980). It was felt that gravel quality parameters based upon the size distribution of sediment in these stratified freeze core samples would provide the best baseline on current spawning gravel quality in the river. Unfortunately, direct sampling of streambed gravel composition was uncommon in the mid-1960's and was not done during the OSGC baseline study.

Gravel Permeability Measurements

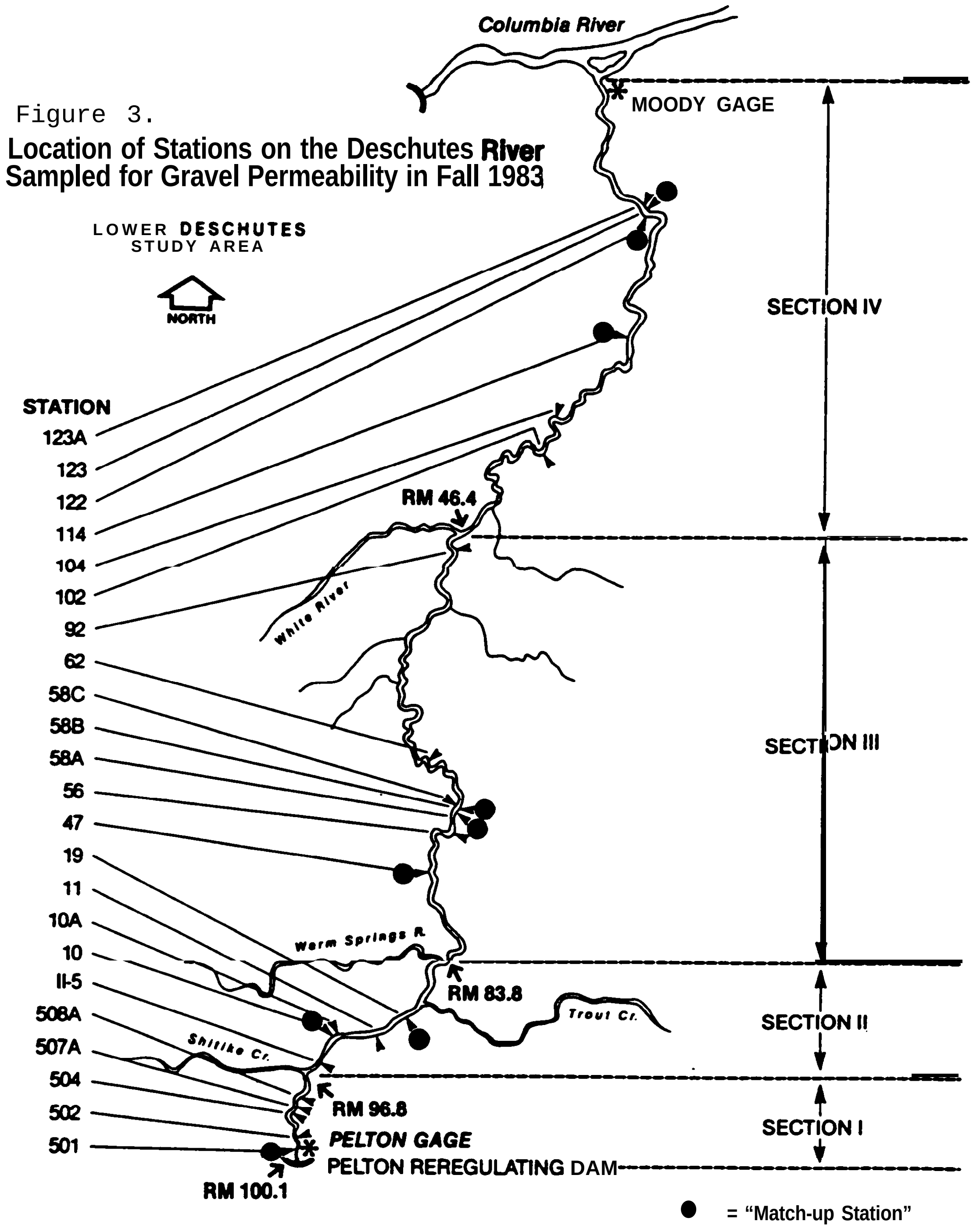
Gravel permeability data collected during the OSGC study were obtained through a search of inactive ODFW files. These data were examined and stratified to produce data sets which could be compared to permeability data collected during this study. It was reasoned that since spawning gravel exhibits seasonal changes in measured permeability related to discharge patterns and the movement of sediments, only data gathered in the same seasons could be legitimately grouped and compared. Stratification resulted in the creation of separate data sets for measurements obtained by the OSGC in the spring (March through June) and during the fall (September through November).

The permeability data in each of the sets collected by Aney et al. (1967) were reanalyzed to account for the interdependence of replicate measurements and the effect of temperature on apparent gravel permeabilities. All OSGC data were stored on permanent IBM tape at the BPA Computer Center in Vancouver, Washington.

Data on the permeability of spawning gravel in the lower Deschutes were collected at 23 spawning bars between 31 August and 31 October 1983 (Figure 3; Appendix III). Nine of these bars were sampled intensively during the OSGC baseline study and served as "match-up" sites to enhance comparisons between current river conditions and those found during the OSGC study. The other 14 stations were selected to complete representative groups of at least five spawning bars for each of the four study sections. Given the gravel composition of areas wetted during September and October of 1983, these 14 "unmatched" stations were suited primarily for spawning by fall chinook salmon.

Twenty point samples of gravel permeability were taken at each station using Mark VI groundwater standpipes (Figures 4 and 5) developed by Terhune (1958) and techniques employed by the OSGC during the baseline study. The standpipes consisted of a stainless steel pipe with 48 perforations arranged in a specific pattern at the lower end, just above a hardened steel driving point. Mark VI standpipes used during this study were subjected to extremely heavy use. Although initially constructed of

Figure 3.
Location of Stations on the Deschutes River Sampled for Gravel Permeability in Fall 1983



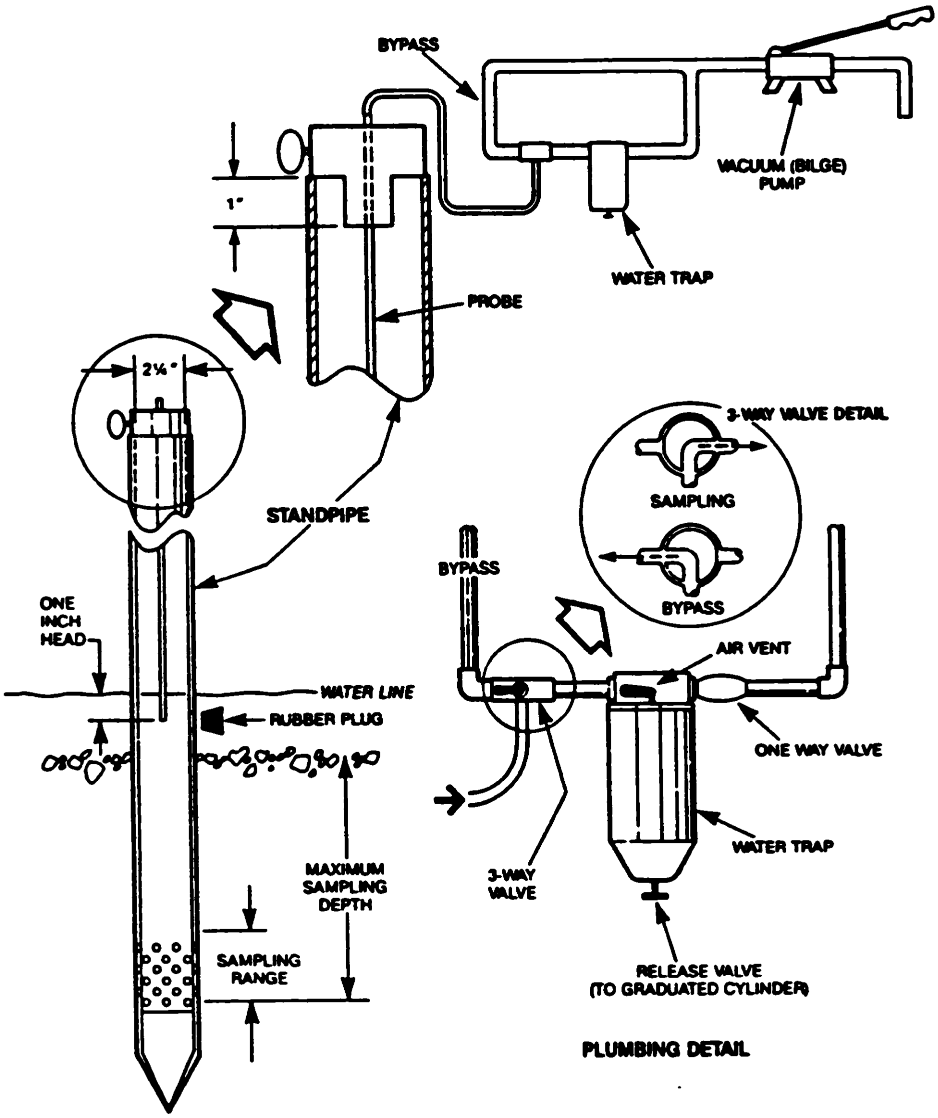


Figure 4. Mark VI groundwater standpipe and water collection device used to sample gravel permeability in the lower Deschutes River, Oregon.

Figure 5. Field operation of the Mark VI groundwater standpipes used to sample gravel permeability during this study.

schedule 40 stainless steel pipe, three of the devices were broken while taking a total of approximately 460 permeability measurements. This necessitated the fabrication of new standpipes from heavier, schedule 80 stainless steel pipe. Driving rods used to sink the standpipes into gravel bars were also damaged and required repairs on occasion. Permeability sampling equipment other than standpipes and driving rods performed satisfactorily, with no malfunctions or breakage suffered during the study.

Gravel permeability measurements were taken at sample points distributed along transects originating at temporary survey hubs established on each gravel bar. A detailed description of the procedure used to measure gravel permeability during this study is presented in Appendix IV.

At most bars the permeability measurements were taken in arrays of six or seven points distributed around each of three survey hubs. In each array, from one to three sample points were distributed along three or four transects radiating from a central survey hub. Some gravel bars, however, could not be sampled in this fashion. At certain stations, gravel dunes created by repeated spawning of fall chinook were separated by troughs too deep to sample. These dune formations consist of a series of elevated bands of spawning gravel perpendicular to flow, with deeper water present between each band or dune. When pronounced gravel dunes were sampled, the permeability measurements were taken at points along transects which cut across the dune structures at oblique angles. The location of each sample point and survey hub was recorded with reference to a permanent benchmark established at each station.

Gravel permeability data collected in Fall 1983 were keypunched, checked and stored within BPA's IBM computer system. These data and those collected in the fall by the OSGC during their baseline study were then analyzed by computer using SAS statistical programs (SAS Institute 1982).

Permeability data for the nine matched-up stations were broken into two groups because of differing years of measurement and of differing effects of the PGE hydrocanplex on gravel recruitment to the stations. The OSGC measured gravel permeability at the one station in Section I both before and after the 1964 flood (Fall 1964;

Fall 1965) but measured permeabilities at the eight downstream stations only prior to the flood (Fall 1963; Fall 1964). Also, Section I lacks an outside source for gravel recruitment while Sections II, III, and IV do not.

The two groups of matched permeability data were tested for statistically significant changes in gravel permeability using separate Analyses of Variance (ANOVA's). Overall, a total of three statistical tests of significance were performed on the permeability data collected. These tests included:

0 A two-way ANOVA (Station X Year) for the eight stations below Shitike Creek sampled in 1983 that were also sampled by the OSGC in both 1963 and 1964. This test was made to determine whether there was a statistically significant change in the permeability of gravel in the Deschutes River below Shitike Creek.

0 A one-way ANOVA (Year effect) for gravel permeability at station 501, which was sampled in 1983, 1964 and 1965. This analysis was performed to determine whether

there was a significant change in the permeability of gravel in the Deschutes between Pelton Reregulation Dam and Shitike Creek.

- A nested ANOVA of data collected in 1983, with stations nested within study sections. This analysis was performed to determine whether observed between-section differences in gravel permeability were statistically significant. Three a priori hypotheses of gravel permeability differences between specific groupings of the study sections were made within this model. The three groupings of study sections were:

    - Study Section I v. study sections II, III, and IV (prime spawning areas immediately below Pelton Reregulation Dam versus spawning areas below Shitike Creek).

    - Study Sections II and III v. Section IV (spawning areas below Shitike Creek not influenced by glacial sediment versus those influenced by glacial flour from White River).

Study Section II v. Study Section III (certain tributaries to Section II are reported to contribute large quantities of fine sediment to the mainstem Deschutes; the Warm Springs River, at the upper end of Section III, has generally clear and stable flows).

The statistical findings of the analyses given above are presented in the Results and Discussion section of this report.

It was initially thought that sampling gravel permeability in the spring would help to quantify changes in gravel quality which may have taken place on the river since the OSGC study. However, small sample sizes in the OSGC data base and experiences with highly variable permeability data collected in Fall 1983 led to a decision by BPA, Buell & Associates, and the ODFW not to sample gravel permeability in Spring 1984.

GRAVEL COMPOSITION

Chinook Spawning Areas

Ten stratified gravel samples were collected at each of 10 potential chinook spawning areas in Fall 1983 (Table 1; Figure 6; Appendix V, Appendix VI). At least two stations were situated in each of the four study sections. The samples were extracted using a modified "tri-tube" freeze core sampler (Figures 7 and 8) and techniques described by Everest et al., (1980). A detailed description of the procedures used to collect stratified core samples of spawning gravel is presented in Appendix IV.

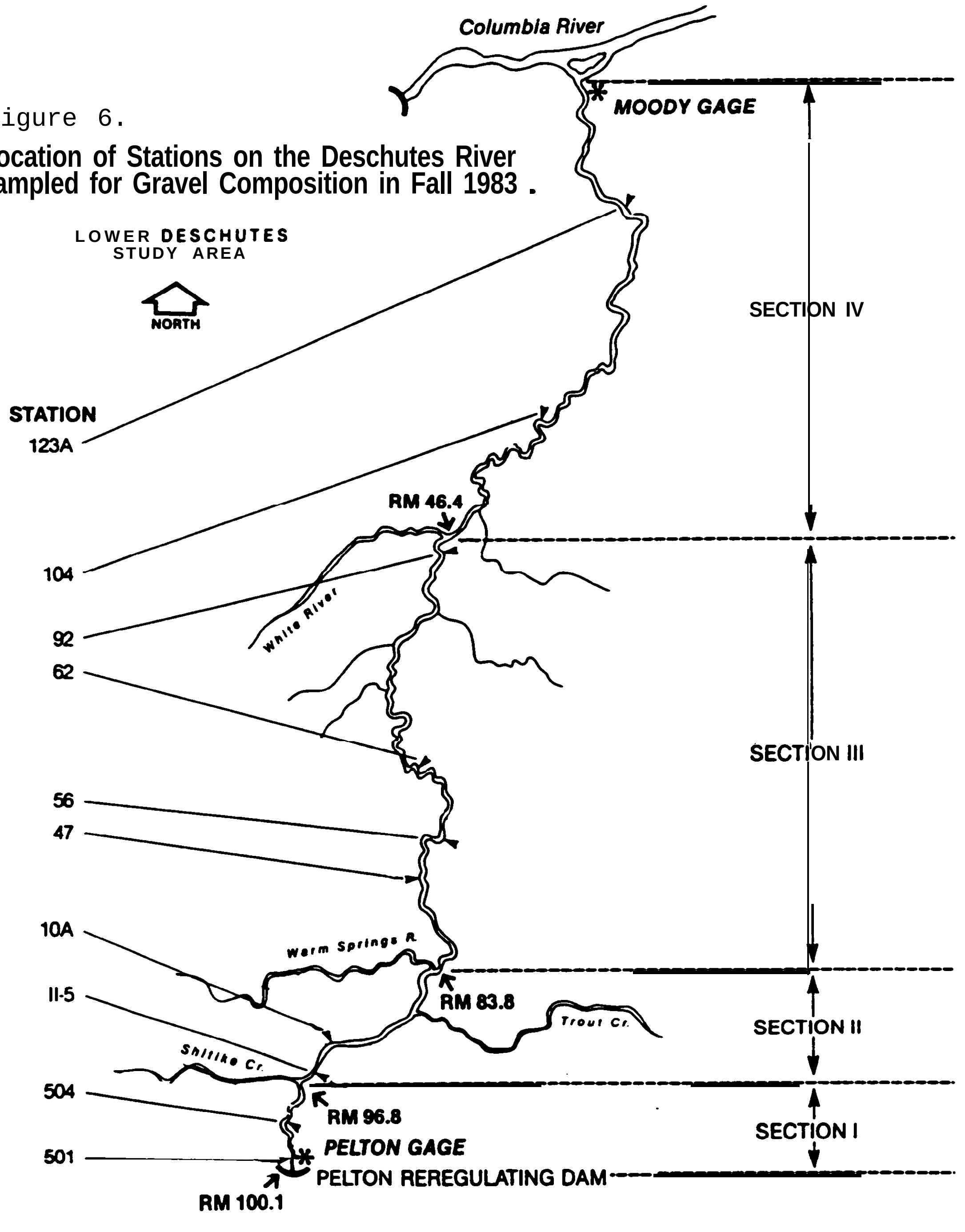
One gravel core was taken from each of three or four sample points scattered randomly around each of three survey hubs at each station. The survey hubs were established in spawning habitat exhibiting physical characteristics within the preference ranges of the species (Reiser and Bjornn 1979). Sample points and survey hubs were established with reference (azimuth and distance) to a permanent benchmark established on the riverbank at each station.

Table 1. Potential fall chinook spawning areas in the lower Deschutes River, Oregon sampled for gravel composition in Fall 1983.

Station Name	Number	Study Section	River Mile
Jackson's	501	I	99.9
Disney	504	I	98.9
Morrison's	5	II	96.4
Below Dry Cr.	10A	II	94.1
Whiskey Dick	47	III	77.2
Newton's Isl.	56	III	70.3
Windy Flat	62	III	65.2
Oak Springs	92	III	47.5
Cedar Island	104	IV	31.1
Fall Canyon N	123A	IV	10.2

Figure 6.

Location of Stations on the Deschutes River Sampled for Gravel Composition in Fall 1983 .



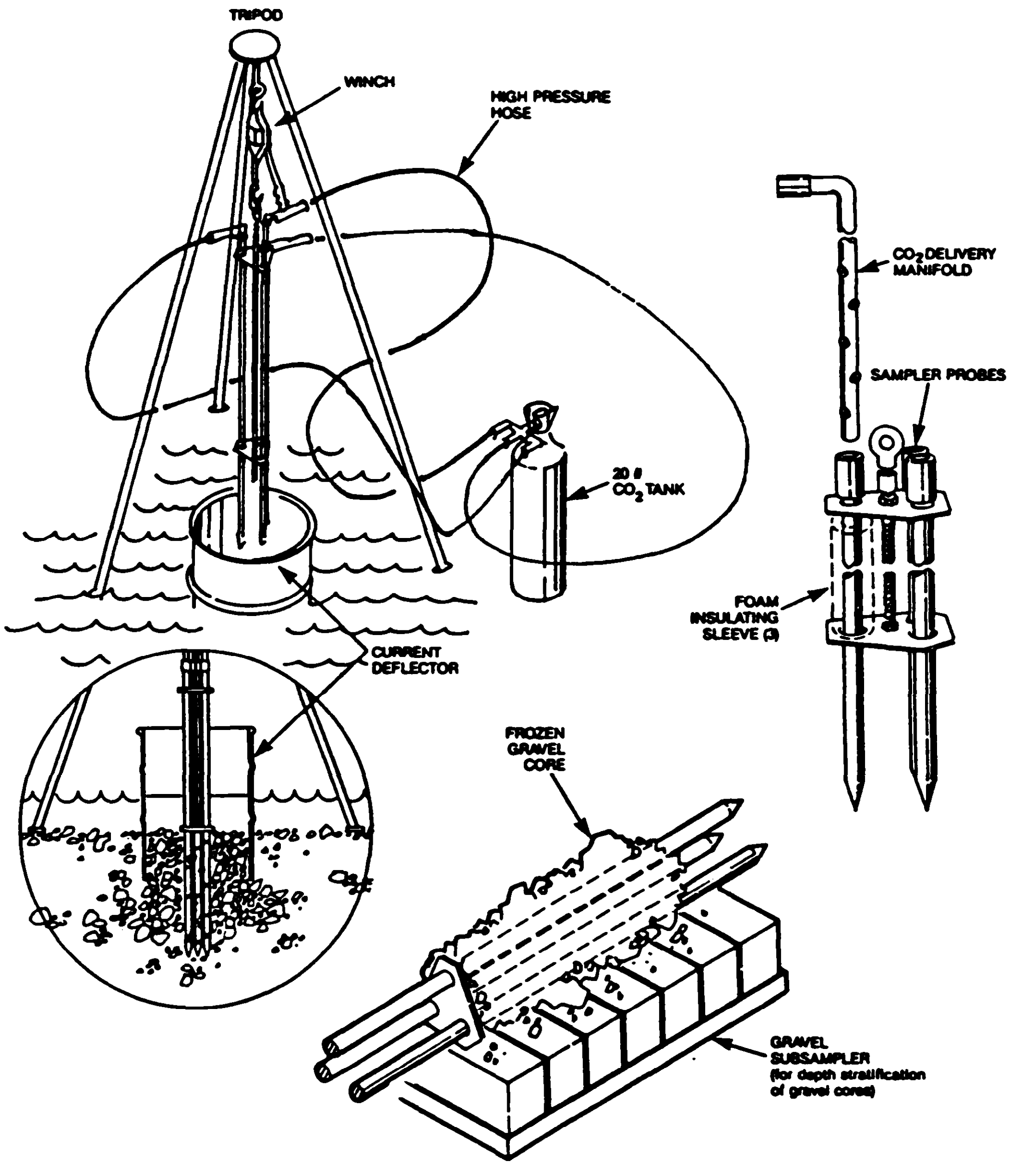


Figure 7. Modified "tri-tube" freeze core sampling equipment used to sample gravel composition during this study.

Figure 8. Field operation of modified "tri-tube" freeze core sampling *gear* used during this study,

Frozen cores of chinook gravel were separated into four 10 cm thick (4 inch) depth strata using a subsampler having removable metal trays (Figure 9). Each depth stratum of substrate was bagged separately and saved for later sieve analysis. Each bag was labelled with a unique code that keyed the enclosed sample to information recorder elsewhere. This information usually included sampling date, station, sample location, water depth and velocity above the point sampled, and comments made at the time of sampling. Water velocities were generally not taken where water depths were less than 15 cm (6 in) due to limitations of the velocity meter used during this study.

Sieve analyses were performed by Northwest Geotechnical Consultants, Inc. of Portland, Oregon. Textural composition of each spawning gravel subsample (i.e. stratum) was determined gravimetrically using sieves having a geometric progression of eleven mesh openings from 0.07 to 76.2 mm (0.002 to 3.0 in). Sediment particles larger than 76.2 mm (3 in) were screened by sieves having mesh

Figure 9, Core sample of angular gravel extracted from a spawning area in Study Section IV. Note the metal trays used to stratify core samples by depth.

openings of 101.6 mm (4 in) and 127 mm (5 in). Results of these analyses were keypunched onto computer tape and transferred to computer disk at BPA's computer center for calculation of gravel quality parameters and statistical analyses.

On examination of the particle size distribution of the chinook gravel samples, it was decided that two sets of gravel quality parameters would be calculated for each depth stratum of each sample. One set of parameters was calculated with only sediment particles less than 101.6 mm in diameter considered and the other with 101.6-127 mm rocks included. The first group of parameters was based essentially upon the contribution by weight of all sediment particles in each subsample and provided the basis for analyses of gravel quality. The second set of parameters was developed because most of the experimental work on salmonid embryo survival has been done with sediment mixtures having no gravel larger than 101.6 mm in diameter.

The 101.6 mm size limit used by most researchers might seem arbitrary, but sediment particles larger than this are not typically found in areas preferred by most spawning salmonids (Lotspeich and Everest 1981). However, detailed analyses performed on gravel quality parameters during this study account for particles up to 127mm in diameter because these are an important component of fall chinook spawning areas in the Deschutes River. Since little research has been done to relate the survival of fall chinook embryos to the composition of coarse gravels which generally surround them in rivers like the Deschutes, excluding the 101.6-127 mm fraction of gravel would not have increased our ability to confidently predict survival rates of fall chinook embryos at the stations Sampled.

Quality parameters calculated for each depth stratum of each gravel sample included: 1) the percentage by weight of fine sediments less than 2.38 mm in diameter; 2) the geometric mean particle diameter (d_g); 3) the sorting coefficient (S_o); and 4) the E'redle Index (F_i).

Geometric mean particle diameter was computed using the equation reported by Lotspeich and Everest (1981):

$$d_g = d_1^{w_1} \times d_2^{w_2} \times . \ . \ d_n^{w_n}$$

Where:

d_g = geometric mean particle size

d = midpoint diameter of particles retained by a given sieve

w = decimal fraction by weight of particles retained by a given sieve

The sorting coefficient (S_o) was obtained by taking the square root of the quotient of the particle size at the 75th percentile rank and that at the 25th percentile rank (Krumbein and Pettijohn 1938; Lotspeich and Everest 1981).

The F'redle Inaex (F'i) is thought to be the gravel parameter most closely related to the survival rate of salmonid embryos. It accounts for the pore size and permeability of gravel which control embryo survival-to-emergence by regulating water movement through gravel interstices. This movement is critical because it delivers oxygen to, and removes metabolic wastes from, the area immediately surrounaing salmonid embryos in the gravel.

Fredle indices were calculated as the quotient of the geometric mean particle diameter and the sorting coefficient (Lotspeich and Everest 1981):

$$F_i = d_g/S_o.$$

The gravel quality parameters for each combination of station and sampling depth were summarized and examined for patterns which might indicate the presence of gravel quality problems in the river. The hypothesis that Fredle indices of the spawning gravel samples differed significantly between study sections and/or stratum depth was tested by Analysis of Variance (ANOVA). A nested and crossed statistical design (Winer 1971), with sampling station as the nested factor, was used to test for the significance of these differences. Within this model, three a priori hypotheses of differences in gravel quality between specific groupings of the study sections were tested for statistical significance. The three groupings of study sections were:

- Study Section I versus the three study sections below Shitike Creek (Study Section I has the greatest spawner densities and lacks gravel recruitment).

- Section IV versus sections II and III (all three sections have gravel recruitment, but gravel quality in Section IV has been reported eslewhere to be quite low.)

- Section II versus Section III (certain tributaries to Section II are reported to contribute substantial volumes of fine sediment to the mainstem Deschutes).

Steelhead Spawning Areas

The freeze core methodology and Fredle indices generated for chinook spawning areas were reviewed by Buell & Associates, ODFW, and the BPA to determine likelihood of developing a statistically sensitive data base on the quality of steelhead spawning gravel in the river. A sensitivity analysis (Lichatowich and Cramer 1979) was performed on Fredle indices calculated by Dr. Fred Everest (USFS - Corvallis Oregon) for steelhead spawning gravels in two Oregon streams to assess their variability. From the review it was felt that freeze core data should be collected at steelheaa spawning areas in the river during 1984. The sensitivity analysis was used to establish a level of effort for substrate sampling of steelhead spawning areas.

The spawning gravel in 13 steelhead spawning areas was sampled in July and August 1984 (Table 2; Fig. 10, Appendix V, Appendix VI) using the same techniques and equipment employed to sample chinook spawning gravel with four exceptions. These exceptions were:

1) Fifteen depth stratified samples were taken at each station.
2) Samples were taken from arrays of three sample points around each of five survey hubs.
3) The triad of sampling probes was driven only 30 cm (12 in) into the riverbed.
4) Each sample was broken into only three 10 cm thick depth strata.

Calculations of gravel parameters were based on gravimetric analyses performed by Northwest Geotechnical Consultants, Inc. Calculations were made in the same way as those for

Table 2 . Potential summer steelhead spawning areas in the lower Deschutes River, Oregon sampled for gravel composition in Summer 1984.

Station Name	Number	Study Section	River Mile
Jackson's	501	I	99.9
Disney	504	I	98.9
Paxton	508A	I	98.0
Morrison's	5	II	96.4
Dry Creek	10	II	94.2
Below Trout Cr.	615	II	86.7
Rim Rock	58A	III	69.2
Eagle Creek	630	III	64.5
Palmer's	73	III	61.8
Below Trestle	95	IV	41.0
Aney #106	106	IV	28.5
Mack's Canyon	109B	IV	23.9
X-Dike Siding	113	IV	21.9

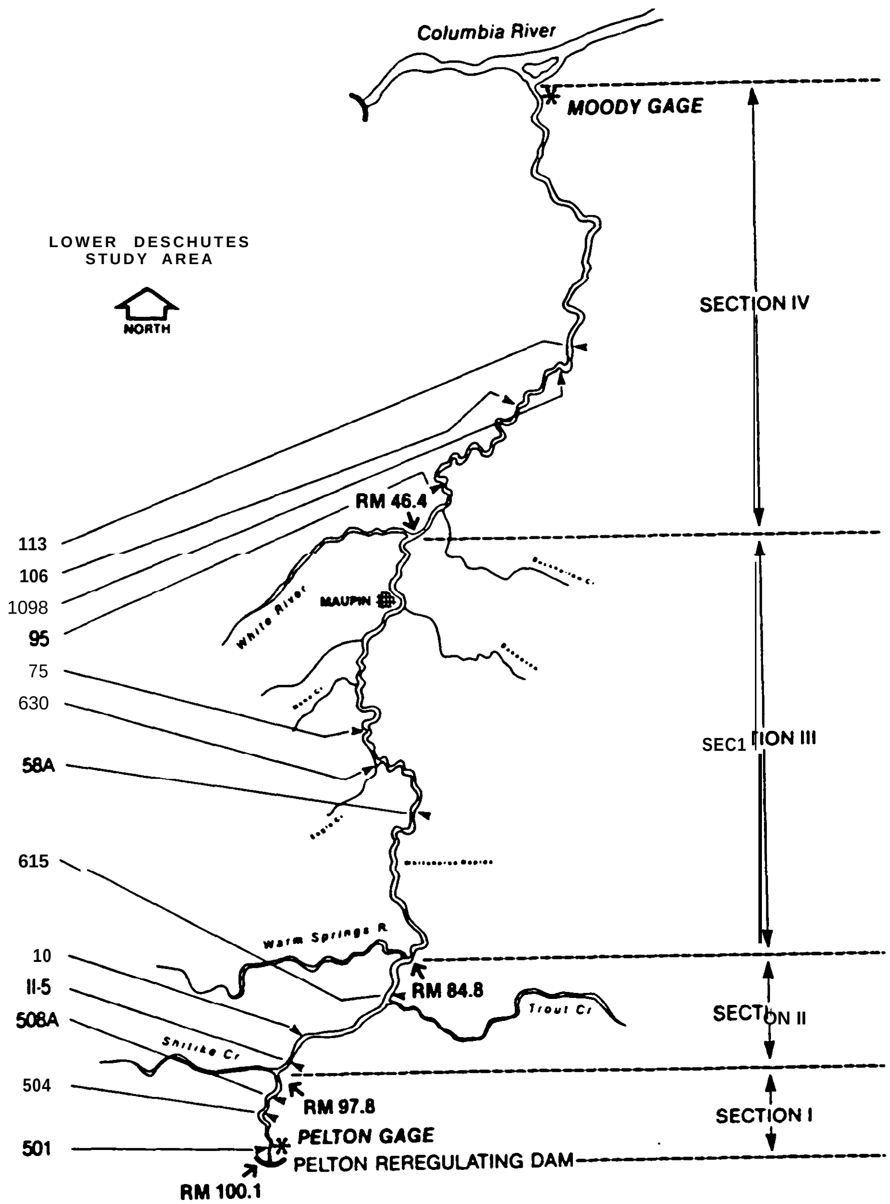


Figure 10. Summer steelhead and resident trout spawning areas in the lower Deschutes River sampled for gravel composition in Summer 1984.

chinook spawning gravel, but only considered gravels less than 101.6 mm (4 in) in diameter because none larger were found in the samples. Statistical analyses performed on the quality parameters calculated for steelhead gravel were the same as those applied to the freeze-core data for chinook gravel.

SPAWNER USE OF HABITAT

Chinook

Historical information on the distribution of chinook spawning activity in the lower Deschutes was obtained from files at the ODFW district office in The Dalles, Oregon. Redd count data collected during and since the OSGC baseline study were then examined for patterns which might be related to the response of spawners to any changes in spawning gravel quantity, quality, and distribution. An effort was made to correlate changes in spawner distribution to possible habitat changes related to operation of the PGE hydroelectric complex and to the 1964 flood. Present patterns of fall chinook use of spawning habitat in the Deschutes were checked to see if they correlated with gravel quality measurements obtained in each of the four study sections.

It was hoped that the locations of chinook redds in the Deschutes could be mapped on air photo overlays. This might have indicated whether certain portions of spawning areas once preferred by spawners are no longer used. Efforts were made by Buell & Associates, ODFW and PGE in late October and November, 1984 to survey chinook redds from a PGE helicopter. However, river and weather conditions during that time period prevented a successful survey.

Steelhead/Trout

Much information on the aistribution of steelhead and resident trout spawning activity in the Deschutes was collected during the OSGC study. However, little historical information could be found on trout spawner distribution either before 1961 or after 1966. To aetermine whether trout miyht be responding to changes in the quantity, quality, and distribution of spawning gravel in the river it was therefore necessary to determine the present distribution of trout spawning activity in the lower Deschutes.

Trout redds in the lower Deschutes were surveyed as soon as river conditions woula allow in 1984. Turbid streamflows delayed the start of the survey until after nearly all steelhead and many resident trout had spawned (Jim Newton, ODFW, The Dalles, Oregon, pers. comm.). For this reason and because steelhead and large trout redds are often indistinguishable in the Deschutes, the counts reflect a combination of summer steelhead and some resident trout spawning activity.

Steelhead and resident rainbow trout redds in the Deschutes between Pelton Reregulation Dam and the Columbia River were counted from 31 May to 13 September 1984. Redds were identified by contour and of ten by color or gravel "brightness". Trout redds can be identified by contour in the Deschutes for many months after excavation provided that they are not disturbed by scouring flows (Aney et al. 1967). When redds were found they were counted and recorded along with their location. Some spawning areas were so heavily used by resident trout that individual redds were indistinct because of superimposition. No attempt was made to approximate the number of redds in these intensely used areas. The location of these gravel bars was recorded along with the notation "mass-spawned". Redd counts and the locations of gravel bars used by spawners were tabulated after the completion of the redd survey.

The results of the trout redd counts were examined to see how steelhead and resident trout in the Deschutes are responding to the spawning habitat available to them. Comparisons were maae between the current spawning distribution for trout and that documented during the OSGC study in an attempt to identify trends which might reflect changes in spawning habitat since completion of the hydrocomplex.

STREAMFLOW

Available flow records for the lower Deschutes River and its tributaries were examined to identify possible causes of changes in the river since the Pelton/Round Butte hydro-complex was completed. Historical records of mean daily flows for U.S. Geological Survey (USGS) stream gages maintained on the mainstem Deschutes near the upper (Pelton gage, RM 100.1) and lower (Moody gage, RM 1.3) ends of the study area were examined to detine recent changes in flow regimes. Streamflow data for USGS gages on Shitike Creek, Warm Springs River and White River examined for changes correlated to those of the mainstem Deschutes. Effects of the complex on mainstem flows during the 1964 flood were reconstructed from PGE data on water storage in Round Butte Reservoir and USGS data for the Pelton and Mooay gages.

A number of computerized analyses of USGS streamflow records were performed by the Water Resources Division of the USGS in Portland, Oregon. Where possible, these analyses broke the historical flow data into two periods, one before and one after full operation of the Pelton/Round Butte complex. The pre-complex period included data from water years 1925 through 1963. Flow records for earlier years were excluded because this was the longest common pre-complex period possible for the USGS gage at Pelton. Data for water years 1964 and 1965 were not included because flows duriny portions of each of those years were hela atypically low in the mainstem Deschutes while Round butte Reservoir was first fillea. The post-complex period included flow data for water years 1966 through 1983.

Of the three USGS gages located on Deschutes tributaries near their mouths, only that on White River has a period of record extending back into the pre-complex perioa. Continuous records for the Shitike Creek and Warm Springs River gages go back no farther than water year 1971. Consequently, no pre-complex examinations could be made of their flow regimes. The "post-complex" periods of record for the Shitike Creek and Warm Springs River gages differ from those for White River, Moody, and Pelton, but provided records used to determine whether data for White River are typical for Deschutes tributaries entering the lower river from the west. There is unfortunately very little flow data available for the lower reaches of streams which enter the lower Deschutes from the east.

Results of the computerized flow analyses were used to generate curves showing both annual and seasonal (monthly) changes in flow regimes experienced at the Pelton, Moody, and White River gage sites since completion of the hydro complex. Shifts in flow timing and magnitude for the two mainstem gages were compared to each other and to those for the White River gage. The comparison between mainstem flows and those in tributaries was made to test the hypothesis that flow changes below Pelton Reregulation Dam are being caused by the Pelton/Round Butte hydrocomplex. In this comparison, the flow records for the White kiver gage served as a control.

Shifts of peak flow timing in the mainstem Deschutes could affect spawning gravel by reducing the synchrony of sediment delivery from tributaries and mainstem flushing flows. For this reason, PGE's inflow/outflow records for the Pelton/Round Butte complex were examined to determine how frequently and to what degree operation of the complex causes short term shifts in peak flow timing.

OSGC REVIEW

Two biologists who worked on the OSGC baseline study participated in a three day survey of the study area with

Buell & Associates staff. These individuals, hr. Warren Aney (ODFW, Region IV Director) and Mr. Al Lichens (ODFW, retired), provided valuable information on observable changes which have taken place on the river since completion of the Pelton/Round Butte complex. They also provided confirmation of our ability to "match" their permeability sampling stations and valuable insights as to what the Deschutes River was like in the 1960's. Results of the three day survey are covered primarily in the Gravel Bar Inventory portion of the Results and Discussion section of this report.

ENHANCEMENT OPPORTUNITIES

A number of opportunities for enhancing or rehabilitating spawning gravel in the lower Deschutes were developed through an examination of the results of habitat improvement work which has been done on other streams. This examination was based on two primary sources of information. Literature on the relative successes or failures of spawning habitat improvement work was reviewed in an effort to determine which established enhancement techniques might prove effective on a river as large as the lower Deschutes. Additional information on enhancement techniques was obtained through discussions with fish biologists in the Pacific Northwest and western Canada who have performed stream improvement work.

RESULTS AND DISCUSSION

GRAVEL BAR INVENTORY

Defining the quantity and distribution of spawning gravel in the Deschutes is difficult. A substantial portion of the spawning gravel present is situated in water too deep to allow careful examination. In fact, certain deposits of spawning gravel in the river were identified during this study only because of the presence of large fall chinook redds which could be seen during aerial counts. Although most of these deposits in deep water consist of large gravels, some of them are suitable for steelhead and resident trout use. Trout are known to spawn in the river at depths as great as 15 feet (M. Montgomery, ODFW, Portland, Oregon, pers. comm.).

The gravel deposits in deep areas of the lower Deschutes make an exact delineation of all spawning habitat in the river impossible. The results given here represent a best effort at identifying the distribution of gravel suitable for use by salmonids in the Deschutes. There are probably a few deposits of spawning gravel in the river which were not identified during this study.

Over 213,500 square yards (sq yd) of spawning gravel were located and mapped during this study. Because of extreme compaction, sedimentation or armoring nearly 20,200 sq yd of this total were classified as poor and unsuitable for spawning. The remaining 193,300 sq yd of gravel can be used by spawning salmon or trout when water depths and velocities meet the requirements of the species. Gravel bar maps showing the location, position in the channel, size, and shape of each gravel bar identified are given in Appendix I. Specific information on the surface area, usability, surface gravel quality and surface gravel composition of each bar can be found in Appendix VII.

Table 3 presents the surface area of gravel in each size and quality class found within each study section. In terms of size, steelhead and resident trout in the Deschutes generally spawn in areas having surface gravel

Table 3. Square yards of spawning gravel suitable (excellent, good, fair) and unsuitable (poor) for salmonid use in the lower Deschutes River, Oregon, 1983-84.

Study Section	Quality Class	Size Class[a] I (1/4-1")	II (1-3")	III (3-6")	IV (6-10")	I-IV (1/4-10")
I	Excellent	0	42	1812	935	2789
	Good	240	2410	11514	5591	19755
	Fair	186	653	2320	2814	5973
	Suitable	426	3105	15646	9340	28517
	Poor	0	0	0	0	0
II	Excellent	386	203	654	85	1328
	Good	1061	7624	15766	9331	33782
	Fair	580	780	15611	8158	25129
	Suitable	2027	8607	32031	17574	61338
	Poor	51	144	1001	1064	2260
III	Excellent	22	153	0	0	175
	Good	575	1656	7036	3140	12407
	Fair	1426	5415	11349	4045	22235
	Suitable	2023	7024	18385	7185	34817
	Poor	346	4801	573	160	5881
IV	Excellent	0	0	0	0	0
	Good	0	205	20104	12236	32545
	Fair	297	1669	20605	14634	37205
	Suitable	297	1874	40709	26870	69750
	Poor	903	6428	3521	1192	12044
ALL	Suitable	4773	20810	106771	60969	193323
	Poor	1300	11373	5095	2416	20184

[a] predominant size range of surface gravel

predominated by materials between l/4 and 3 inches in diameter (6.4-76.2 mm; size classes I and II). Chinook prefer spawning areas with coarser surface gravels dominated by particles between 3 and 10 inches in diameter (76.2-254 mm; size classes III and IV).

Although only qualitative, the classifications of surface gravel quality in each of the four study sections show some important trends. Based on visual appearance, the quality of spawning gravels for trout (classes I and II) was higher at the upper end of the study area than at the lower end. In fact, most of the class I and class II gravels found below White River in Section IV were unsuitable for spawner use because of compaction or heavy sedimentation. The apparent quality of spawning gravels for fall chinook (classes III and IV) was generally highest in Section I, where much of the gravel has been heaped into pronounced dunes by spawning fish. The quality of chinook gravels, like that of trout gravels, appears to decline in a downstream direction.

The apparent quality of class III and class IV gravels below White River is not as low as that of the finer gravels there. This difference is at least partially due to intense spawning activity by fall chinook which has substantially modified the riverbed in a few large spawning areas within the Section. Fall chinook in the Deschutes may be more able to tolerate compaction of their spawning gravels than are steelhead and resident trout. We suspect that fall chinook in the river tend to improve low quality spawning areas or maintain the high quality of good ones through persistent spawning activity.

There is considerably more spawning gravel for fall chinook in the mainstem Deschutes than for steelhead and resident trout. Approximately 87 percent (167,589 sq yd) of the suitable gravel located during this study was of the size preferred by fall chinook. Only about 13 percent of the gravel suitable for spawning (25,556 sq yd) fell into size classes I or II, those preferred by resident trout and steelhead.

Based on results of the spawning gravel inventory, there is more gravel suitable for spawning salmonids in sections IV (69,750 sq yd) and II (60,061 sq yd) than in sections III (34,817 sq yd) or I (28,517 sq yd). Sections II (10,607 sq yd) and III (9,247 sq yd) have substantially more gravel suitable for trout spawning than either Section I (3531 sq yd) or Section IV (2173 sq yd). Study Section IV has considerably less trout spawning gravel than any of the other three study sections in spite of being the largest Section in the study area. In contrast, the total area of chinook spawning gravel is greatest in Section IV (67,579 sq yd), slightly lower in Section II (49,454 sq yd), and considerably lower in study sections I (24,986 sq yd) and III (25,570 sq yd).

The surface areas of suitable gravel given in Table 3 provide a rough indication of how spawning gravel is distributed in the Deschutes. However, the lengths of the four study sections differ enough that the surface areas given do not indicate the quantity of gravel suitable for spawning in a typical reach within each study section. The area of suitable gravel of each size class in an average reach within each Study Section is depicted graphically in Figure 11.

Figure 11 shows that there is more spawning gravel for both fall chinook and trout per river mile in Section I, than in any of the other three study sections. This corresponds

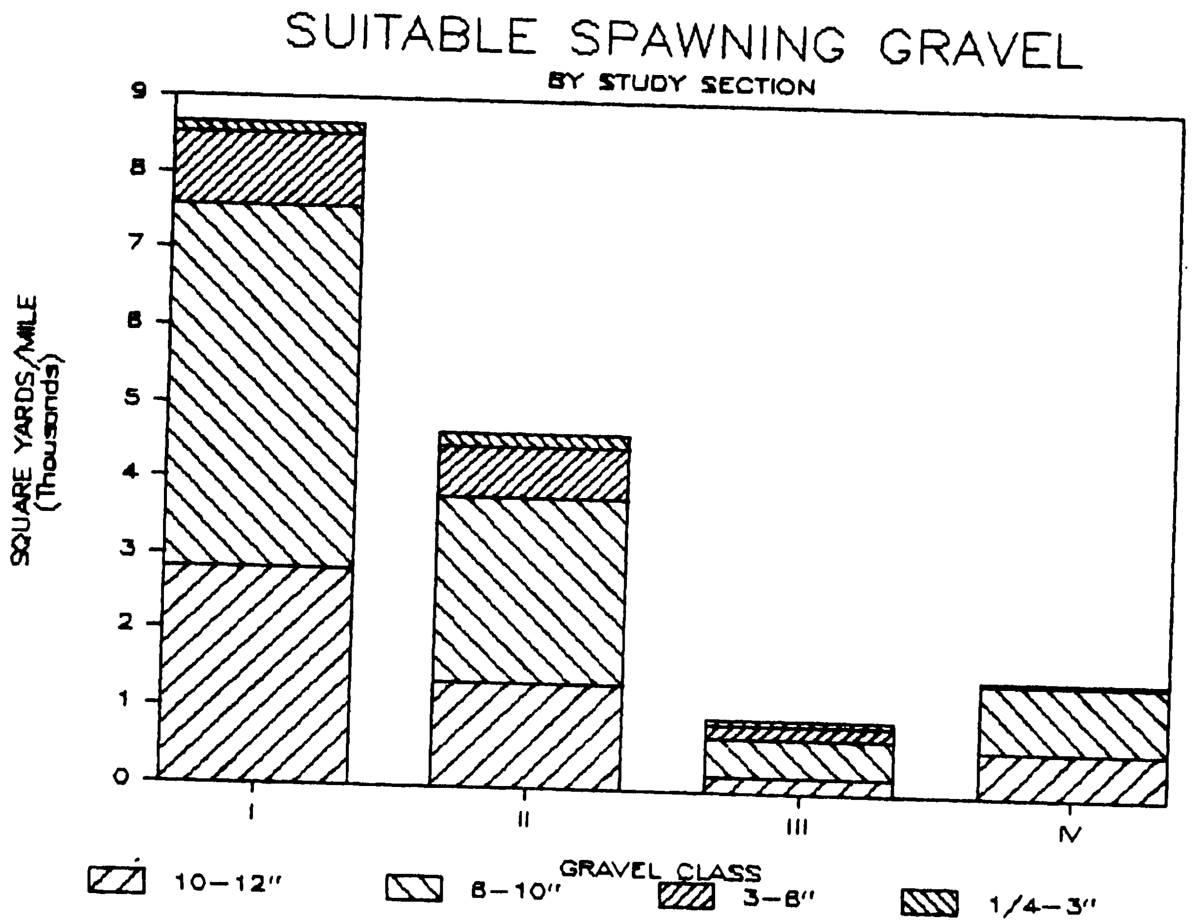


Figure 11. Surface area of spawning gravel per river mile in each of four study sections of the lower Deschutes River, Oregon, 1983-84.

with the fact that the 3.3 miles of the lower Deschutes above Shitike Creek has long been considered the best reach for salmonid spawning in the entire study area (James Newton, ODFW, The Dalles, Oregon, pers. comm.). Study Sections below Shitike Creek show a relatively steady decrease in the average quantity of trout spawning gravel per river mile with increasing proximity to the river mouth.

This declining trend apparently does not hold true for chinook spawning gravel. Although the average reach in Section III contains less suitable spawning gravel for fall chinook than that in Section II, the average reach in Section IV contains more chinook spawning gravel than that in Section III. This result was somewhat unexpected because both the quality and quantity of spawning gravel in Study Section IV have long been thought to be low. We attribute this discrepancy to the fact that most spawning gravel in Section IV is found within a few large spawning areas, with many long reaches completely lacking suitable spawning sites.

The uneven distribution of spawning gravel in the Deschutes below White River is not unique to that section of the river. Figure 12 gives the distribution of chinook and trout spawning gravel in the lower Deschutes River by one mile reaches. Gravel suitable for trout spawning is most abundant immediately below Pelton Reregulation Dam in Section I, and in relatively protected areas below tributaries which contribute finer gravels to the mainstem. Most trout spawning gravel in the river was associated with islands, side channels and areas along the river margin protected from scouring by high flows. The largest deposits of class I and II gravels outside of Section I are found below Shitike (RM 96.8), Dry (RM 94.3), Trout (RM 87.2) and Eagle (RM 64.5) creeks. In fact, one mile reaches of the river at Dry Creek (RM 94-95) and below Eagle Creek (RM 61-62) each account for approximately 12 percent of all the trout spawning gravel located during this study. below Nena Creek (RM 57.8) in Section III and throughout Section IV there are few deposits of trout spawning gravel in the mainstem Deschutes.

The greatest accumulations of spawning gravel suited for fall chinook use are in broad depositional reaches of the Deschutes River, where flow is relatively uniform. This type of area occurs at Annie Dick (RM 85.4) in Section II

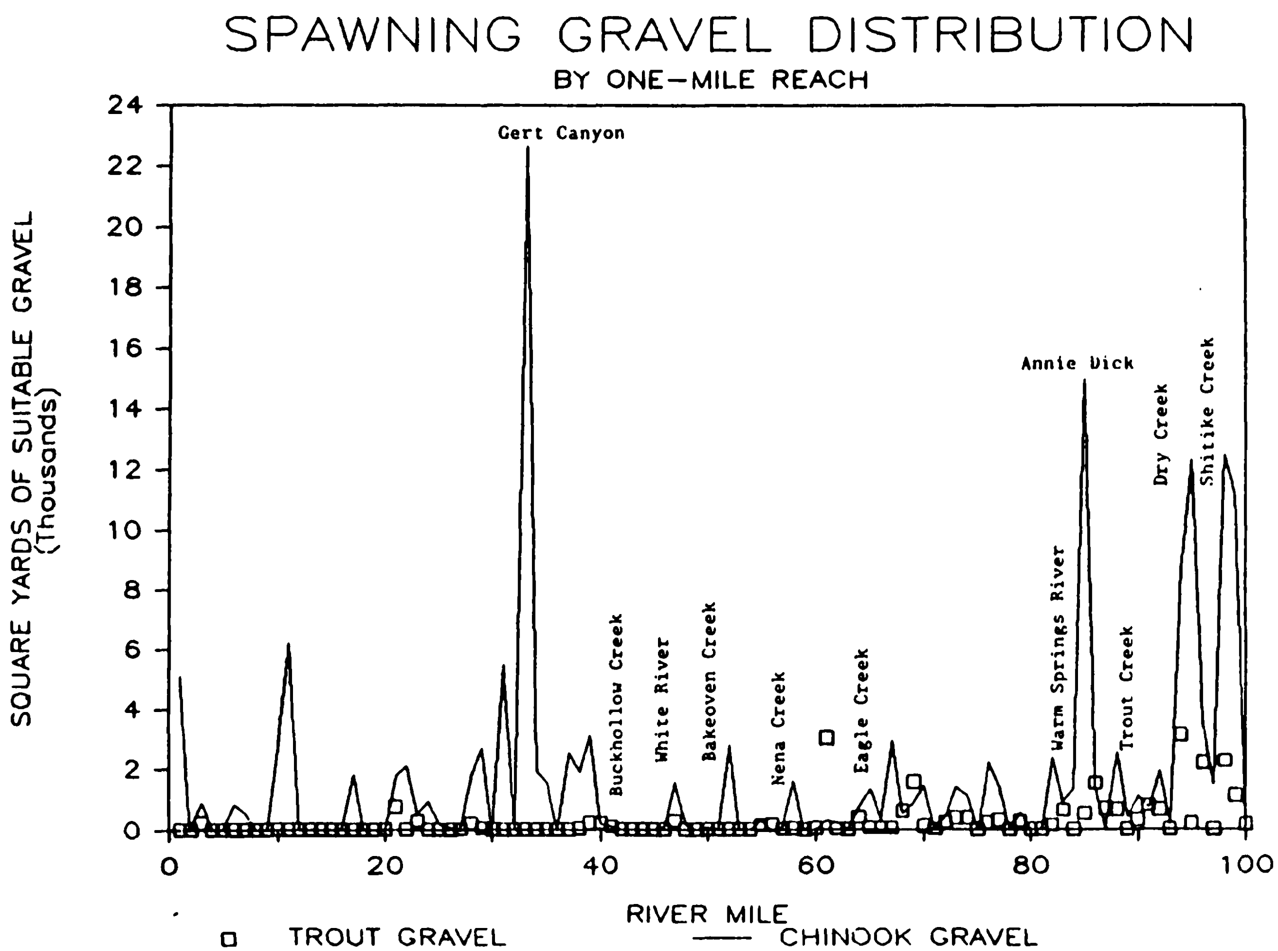


Figure 12. Surface area of gravel suitable for use by spawning trout or chinook salmon in the Deschutes River, Oregon given by one-mile reach.

and at Gert Canyon (RM 33.0) in Section IV. Each accounts for over a fourth of the chinook spawning gravel in their respective study sections.

Some deep water spawning areas available to chinook may not have been identified during this study. Uncataloged deposits of chinook spawning gravel would most likely be present in sections III or IV.

Comparison to OSGC Study

During their baseline study, the OSGC documented the status of spawning habitat for salmonids in the lower Deschutes River. When this study began in 1983, it was unclear precisely how the OSGC had documented the quantity and distribution of spawning gravel in the river during the 1960's. For this reason, Buell & Associates drew conclusions regarding the OSGC's methods and rationales based upon discussions with members of the original OSGC study team and a limited amount of background material which was available at that time. Unfortunately, a few of these conclusions, which will be described later, were not entirely correct.

After developing an approach to collecting data which could be compared to historical baseline data on the quantity and distribution of spawning gravel in the Deschutes, a major effort was undertaken to relocate historical data. Throughout this study, it was thought that all important OSGC data would be located. However, the effort to find historical OSGC data continued for the duration of this study and met with only partial success. Important OSGC information which might have given valuable insights into how the quantity and distribution of spawning gravel in the river have changed over time was never located.

Section I

Because the OSGC baseline estimate of the amount of spawning gravel present in Section I was based on air photo interpretations, it is comparable to present estimates of the area of suitable spawning gravel in the same reach. Based on the results of our gravel inventory, there are approximately 28,500 sq yd of gravel suitable for salmon and trout spawning in Study Section I.' This figure is about 26 percent less than the 38,700 sq yd of suitable spawning gravel identified by the OSGC (Aney et al., 1967). Since the OSGC estimate was made after the 1964 flood, it seems apparent that Section I has been a net exporter of spawning gravel since the OSGC Study.

The fact that there appears to have been a reduction in the surface area of suitable spawning gravel in Section I is not surprising. Gravel recruitment problems often lead to losses of spawning gravel immediately below dams. The Pelton/Round Butte hydrocomplex has stopped the migration of gravel originating from the Deschutes drainage above Pelton Reregulation Dam down the lower mainstem Deschutes. Peak flows discharged from the complex can move gravel below the Reregulation Dam downstream, but the PGE dams prevent natural replacement of this gravel from upstream sources.

Erosion of islands in Section I over the last 20 years has partially offset losses of gravel caused by peak flows and a lack of natural gravel recruitment from areas farther upstream (Figure 13 & 14). Discussions with members of the original OSGC study team and an examination of aerial photographs indicates that the islands in Section I are getting smaller. However, localized gravel recruitment from these islands is not entirely beneficial. The islands are a non-renewable source of gravel which is being

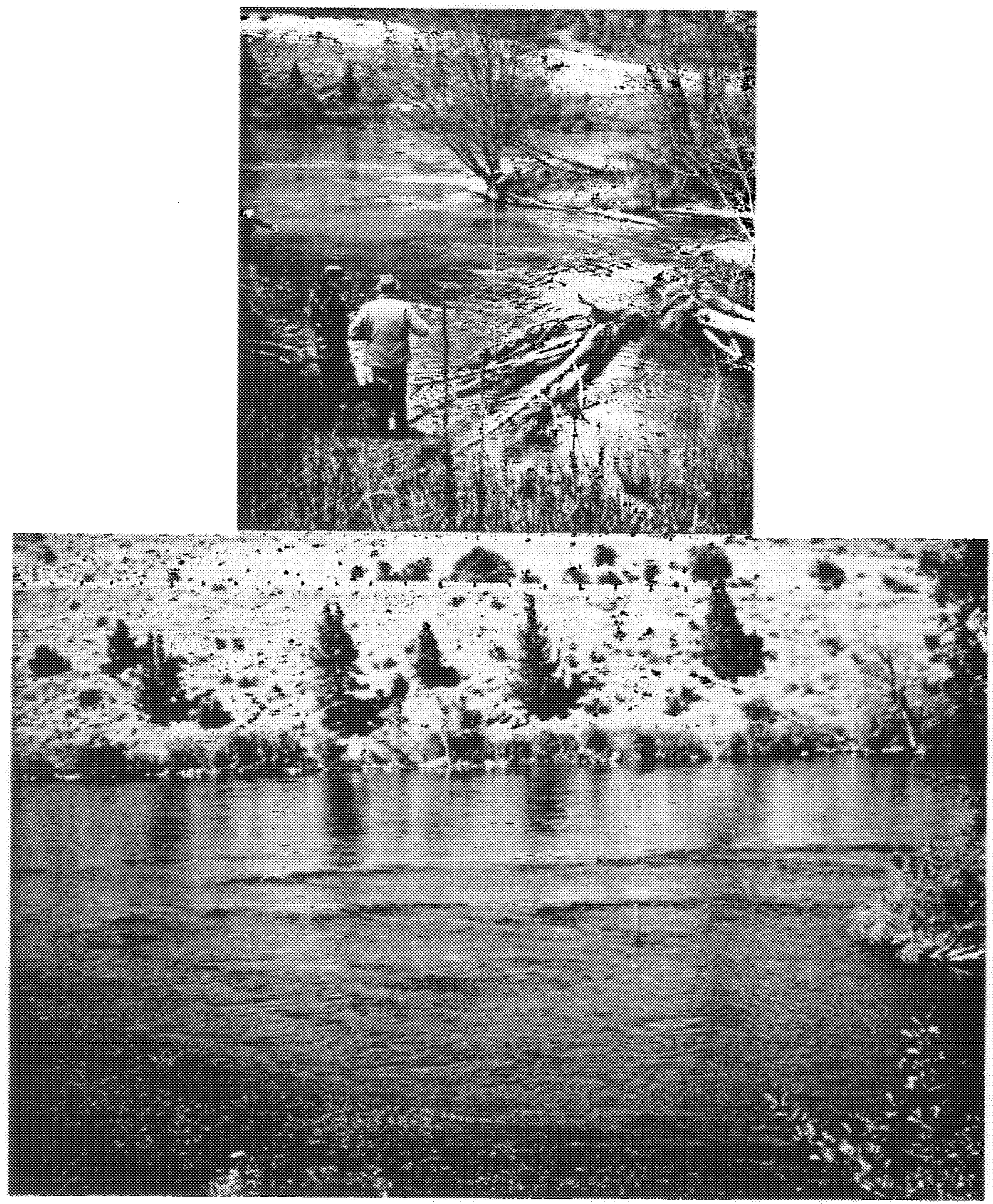


Figure 13 & 14. Station 504 (Disney; Section I; RN 98.9) as it appeared during the mid-1960's (upper photo) and as it appeared in 9984 (lower photo). Note that the head of the island shown in the photos has been eroded over time, depleted. As the islands in Section I gradually disappear, so too will the finer gravels and steelhead or resident trout spawning habitat associated with them.

Not all of the apparent reduction in spawning gravel area within Section I has necessarily been due to gravel exportation. Spawning gravel also appears to have been lost to invading or encroaching aquatic and emergent vegetation (see photos in Appendix XIII). The two types of gravel loss may be related, with a deepening of the thalweg causing reduced velocities along river margins which then allow aquatic vegetation to encroach.

The difference between present estimates of spawning gravel area for Section I and those reported by the OSGC are substantial. However, changes in gravel bar distribution in the mainstem Deschutes immediately below the Pelton Reregulation Dam have not been particularly dramatic. Much of the apparent reduction in suitable gravel area may reflect a reduction in average gravel bar area as opposed to losses of entire spawning areas.

A comparison of recent high resolution aerial photographs and historical oblique aerial photographs shows that there has been little change in the distribution of main channel gravel bars in the immediate vicinity of Pelton Reregulation Dam. This could indicate that a heavy armor layer has developed on those bars which recent peak flows have been unable to completely remove. However, it does raise questions about the magnitude of the scouring forces below the Reregulation Dam and the resulting tendencies for changes in gross hydraulic geometry.

There are no quantitative data from which any conclusions can be drawn on how the 1964 flood affected the quantity and distribution of spawning gravel in Study Section I. There was surely a net loss of gravel from the reach during that event. Members of the OSGC study team put the effects of the flood on Section I into perspective during their survey of the river in 1984. They noted that spawning habitat in this reach of the river has changed far more in the time since their baseline study than it did during the 1964 flood. OSGC team members noted that islands in the reach- have shortened through erosion (Figure 13 & 14), gravel texture in some areas (particularly in certain side channels) has become much coarser, side channels have become wider, certain chinook spawning dunes have become more pronounced, and that the once heavily used gravel bar immediately below Pelton Reregulation Dam is now rarely used by spawning fall chinook.

Sections II, III and IV

The OSGC based its estimates of the surface area of spawning gravel present in sections II, III and IV on gravel survey data similar to those collected during this study. However, after our field activities were completed we found that the OSGC's baseline estimates of the spawning gravel area in each of the lower three study sections were not based on gravel surveys which subsampled the available habitat within each of the sections. Instead their estimates were calculated as expansions of the spawning gravel area of a hypothetical "average" Deschutes River spawning bar. The characterisitics of this hypothetical gravel bar were derived from gravel survey data collected at a total of 25 gravel bars in 5 one mile reaches of the river (Appendix IX).

The OSGC's estimates of spawning gravel area were extrapolated from the "average" spawning bar based on the number of gravel bars thought to be present in each of the lower three study sections after the 1964 flood. Thus the

OSGC's estimates, upon which our analyses of changes in spawning gravel quantity and distribution were to be based for sections II, III and IV, are simply weighted reflections of the numbers of suitable gravel bars thought to be present in these sections.

The OSGC estimates of the quantity of spawning gravel in each of the lower three study sections were developed in a short period of time to provide an indication of the relative abundance of spawning gravel at the upper end of the study area. However, the estimates were not intended to be used as the basis for an analysis of changes in the quantity and distribution of spawning gravel in the Deschutes. In fact, estimating the quantity of spawning gravel present in the Deschutes was not a major objective of the baseline study (Warren Aney, ODFW, LaGrande, Oregon, pers. comm.).

In checking our comparisons between gravel inventory data gathered during this study and those of the OSGC study, we came to a full understanding of the "average" bar expansion algorithm previously described. This understanding raised serious questions about the accuracy of the OSGC estimates of the surface areas of spawning gravel present in sections

II, III, and IV during the mid 1960's. We question the algorithm used to develop the OSGC estimates for these sections for two major reasons. First, it is unlikely that the hypothetical "average" bar fully accounted for a small number of very large gravel deposits in the river. Second, estimating the relative distribution of spawning gravel based solely on the number of gravel bars thought to be present in each study section did not account for between-section differences in gravel bar characteristics which prevailed in the aftermath of the 1964 flood.

Gravel survey forms completed by the OSGC were not found. The information on these forms was used by the OSGC to define the physical characteristics of the "average" bar and, if found, would have been used to analyze changes in the quantity and distribution of spawning gravel within sections II, III, and IV. Finding these completed forms would have allowed direct comparisons of current and baseline conditions in five specific one mile reaches of the Deschutes and for 25 specific gravel bars.

Without the survey data used to generate the OSGC estimates of spawning gravel area, there were no accurate historical records to which our results for sections II, III and IV could be compared. Other OSGC field data were found, but they only gave approximate gravel bar dimensions and were usually based upon visual estimation of bar legths and bar widths. The data found were generally not based on direct measurements of spawning gravel areas (Warren Aney, ODFW, La Grande, OR, pers. comm.).

Given the nature of the historical data which were found, two approaches to assessing changes in the abundance and distribution of spawning gravel in sections II, III, and IV were developed. Neither approach yielded quantitative results in which much confidence could be claimed. First, OSGC estimates made using the "average" bar algorithm and reported by Aney et al. (1967) were compared directly to our results. Second, OSGC field data found during this study were compiled and used to the extent possible to estimate changes which have taken place in these sections since the mid-1960%.

Table 4 shows the results of qualitative comparisons between our findings and the surface areas of spawning gravel reported by the OSGC (Aney et al. 1967) to have been present in sections II, III and IV after the 1964 flood.

Table 4. Results of comparisons between estimates of the surface areas of spawning gravel present in each of three study sections of the lower Deschutes River, Oregon, during the mid-1960's (Aney *et al.* 1967) and during this study (1983-84).

Study Section	Result of Comparison Between Between Current and Historical Estimates of Spawning Gravel Area
II (RM 83.8 - 96.8)	increase in area *
III (RM 46.0 - 83.8)	decrease in area *
IV (RM 0.0 - 46.0)	increase in area *

* These qualitative results are based upon comparisons involving some data which may not be accurate. The historical data were collected more to indicate the relative abundance of spawning gravel in each section than to document absolute abundance of spawning gravel.

These results are given only to provide perspective for those interested in knowing how they compare to the results of other comparisons to be presented later. For reasons already stated, confidence in the results of these comparisons is not strong.

Available OSGC field data on spawning gravel area were collected primarily during a few spawning ground surveys made on the Deschutes between 1961 and 1966. The data consist of locations, estimated surface areas and approximate gravel sizes for each deposit of spawning gravel seen by the OSGC during these surveys. Unfortunately, not all of these data were recorded in a similar manner. Therefore, initial interpretations of these data were-discussed with members of the OSGC study team. Results of these discussions indicated that our initial interpretations of the historical data could be improved upon by taking three factors into account.

Interpretations of OSGC field data were changed to account for the following factors:

- Many of the OSGC field data gave maximum rather that mean gravel bar dimensions (Warren Aney, ODFW, LaGrande, Oregon, pers. comm.). To account for this, an empirically derived constant (0.82) based on OSGC field measurements (from p. l-43 in Aney et al., 1967) was applied to the product of each appropriate spawning bar's maximum length and width to estimate its surface area.

- In a few cases there were replicate records for the same spawning bar for the same time period. In those instances, the smaller of the two surface areas recorded for the bar was assumed to be a portion of the larger area unless OSGC field data specifically noted otherwise.

- The OSGC field data were numerical but were collected with the ultimate intent of making a qualitative determination of how spawning gravel was distributed in the river (Warren Aney, ODFW, La Gra'nde, OR, pers. comm).

Given limitations of the OSGC field data for sections II, III and IV, it was apparent that certain comparisons which could be made using them were more likely to be dependable than others. Comparisons within the OSGC data themselves should be more dependable than comparisons with other data (e.g data collected during this study) because the OSGC data were all collected by the same individuals. Trends suggested by differences between the OSGC field data and data collected during this study could come from a variety of sources other than real changes in river conditions. Between-study differences suggested by comparisons of our results to compilations of the OSGC field data cannot be claimed to reflect definite quantitative changes in the surface area of spawning gravel in the lower three study sections.

Table 5 contrasts our results with a compilation of OSGC field data on sections II, III and IV which were collected both-before and after the 1964 flood. All values presented in the table are for the area of gravel suitable for spawning without regard to streamflow conditions over the gravel. The gravel classification systems used by the OSGC

Table 5. Estimates of the surface area (in square yards) of gravel suitable for use by spawning salmonids in three study sections of the lower Deschutes River, based upon field data collected by the OSGC in the mid-1960's and upon the spawning gravel inventory conducted by Buell & Associates in 1983 and 1984.

		OSGC Field Data[a]		
Study Section	Gravel Class	Before 1964 flood (1961-64)	After 1964 flood (1965)	(1983-84)
II	I-IV (l/4-10")	130,000	80,000	61,340
III	I-IV (l/4-10")	122,000	86,000	34,817
IV	I-IV (l/4-10")	153,000[b]	--[bc]	69,750

a OSGC estimates of suitable area were often based upon visual approximations of surface area.

b Incomplete coverage of Study Section IV.

c A cursory inventory of spawning gravel in Section IV conducted soon after the flood indicated that the surface area of spawning gravel may have been reduced by as much as 80% during the flood.

were often not the same as that used during this study, preventing a determination of the area of gravel suitable for use by chinook or by steelhead.

The OSGC figures given in Table 5 suggest that there was a substantial reduction in the surface area of usable spawning gravel (classes I-IV) within sections II and III as a result of the 1964 flood. Although the information available for flood-related changes in the quantity of spawning gravel in Section IV is very limited, it is known that the area of usable gravel below White River also declined dramatically during the flood.

During the 1964 flood there was a prodigious volume of gravel and fine sediment contributed to the Deschutes by three major tributaries in Section II: Shitike Creek , Dry Creek and Trout Creek (Aney et al., 1967). This material was deposited in many locations in Section 11,degrading spawning habitat and altering the contours of a number of gravel bars used by spawning fish prior to the flood (Al Lichens, ODFW-retired, Estacada, Oregon, pers. comm.).

The 1964 flood also had a dramatic effect on the Deschutes below the Warm Springs River in sections III and IV. There are signs of damage done by the flood in these sections that can still be observed. The 1964 flood completely removed some spawning bars in the river and dramatically altered the contours and composition of others (Aney _et al_., 1967). In numerous instances gravel once suitable for spawning was replaced by heavy deposits of unsorted bed materials (Warren Aney, ODFW, La Grande, Oregon, pers. comm.). Many of the gravel bars in these two sections today are composed of large, poorly sorted materials which cannot be used by spawning fish. It is unclear just how many of these bars have this characteristic because of persisting effects of the 1964 flood as opposed to being caused by prevailing hydraulic conditions.

The figures in Table 5 suggest that spawning areas in sections II and III have not only failed to recover from the 1964 flood, but have continued to decline in area since that event. However, given the possible inaccuracy of the historical data, the apparent post-flood declines in spawning area could partially be artifacts of our analyses. The surface areas presented indicate smaller changes for Section II than for Section III, in spite of the greater proximity of Section II to the PGE hydroelectric complex. In addition, the suggested declines conflict with statements made by members of the OSGC study team in 1984 to the effect that many areas within these sections appear to have recovered somewhat from devastation suffered in 1964. Part of the apparent differences might be attributable to an ability on the part of the OSGC to identify spawning areas in deep water which were not visible under the relatively high flow conditions which prevailed during this study.

Information presented in Table 5 gives no indication of how spawning habitat in Study Section IV has responded to river conditions prevailing since the completion of the baseline study. However, the OSGC apparently found almost twice as much suitable spawning gravel in Section IV before the 1964 flood as was found there during this study. A difference of this magnitude would probably not result from possible inaccuracies in the historical data. This suggests that either we failed to catalog a large quantity of spawning gravel identified by the OSGC during their surveys of Section IV, or that a substantial loss of spawning gravel occurred there either during or in the years following the 1964 flood. The best explanation for the difference is a dramatic reduction in the area of spawning habitat within Section IV caused by the 1964 flood.

ODFW biologists who assisted us during this study were able to help identify many deposts of spawning gravel in deep water but may have been unfamiliar with other existing deposits because they had not surveyed the entire river from the air as OSGC biologists did during the original baseline study. Aerial overflights of an approximately 15 mile reach of Study Section IV in the Fall 1984 indicated that there were a few spawning areas which neither Buell & Associates nor the ODFW had identified previously. However, it is doubtful that the presence of unmapped deep deposits of spawning gravel could fully account for apparent historical reductions of spawning gravel within Section IV, or even within Section III. The differences between our data and the OSGC field data for these two sections are too large for this to be the case.

Field data summarized in Table 5 were also compared to our results both on a sub-reach and on an individual bar basis (see Appendix X). The quantitative results of these comparisons could be very misleading due to the nature of the historical data base and will therefore not be described here. Although only subjective and possibly incorrect, the qualitative results of these comparisons suggest that in addition to previously identified changes in the quantity or distribution of spawning gravel:

- The 1964 flood may have had a particularly damaging effect on spawning habitat in the Deschutes River between Trout Creek and the Warm Springs River.

- There may have been a considerable increase in the amount of spawning habitat in the Deschutes River between Warm Springs River and Whitehorse Rapids.

- The rate at which the Warm Springs River delivers gravel to the mainstem Deschutes may have been reduced as a consequence of the 1964 flood. This possibility is supported by observations that the channel of the Warm Springs River is heavily armored near its confluence with the Deschutes River and shows little evidence of gravel transport. In addition, gravel deposits in the Deschutes River immediately downstream of the Warm Springs River are composed of strikingly angular rock material. Whether the Warm Springs River historically transported large volumes of gravel to the Deschutes is unclear at the present time.

o A drop in gravel delivery rate similar to that hypothesized for the Warm Springs River may have taken place in Trout Creek. Trout Creek was channelized along much of its length by the U.S. Army Corps of Engineers in the aftermath of the 1964 flood. However, data on spawning gravel in areas below Trout Creek are not nearly as suggestive of a changed rate of gravel delivery as those for areas below the Warm Springs River are.

Encroaching Vegetation

There is presently a substantial amount of aquatic and emergent vegetation growing at many locations in the lower Deschutes River. This vegetative growth is most prevalent at the upper end of the study area, particularly in sections I and II. It is less frequently found in the Deschutes downstream of White River (Section IV). Although it was initially thought that the vegetation was growing in response to regulated streamflows, increased nutrient loading of the river, or decreased spring-time turbidity caused by a settling of fine sediment in Round Butte Reservoir, this may not be the case.

The Deschutes River has historically had notable growths of emergent and aquatic vegetation. Members of the OSGC study team noted during their tour of the river in 1984 that there did not appear to be much more vegetation in the river then than there was at the time of their baseline study. However, their observations were complicated by a possible removal of vegetation from the streambed by relatively high flows experienced from water year 1982 through water year 1984.

E'rom the discussion above it is apparent that the magnitude of recent changes in the amount of vegetation growing in the Deschutes River is unclear. We believe that there is more vegetation encroaching upon gravel bars in the river now than before construction of the Pelton/ Round Butte hydroelectric complex. This belief is based upon discussions with long-time residents of the Deschutes Basin and personal observations made on the abundance and distribution of encroaching vegetation in the Deschutes.

We are unaware of any historical data which could confirm or disprove this belief.

Spawning Dunes

Early in this study it was noted that portions of the riverbed in many major fall chinook spawning areas in the Deschutes River are characterized by parallel bands of elevated gravel oriented approximately perpendicular to streamflow. These bands or "dunes" of spawning gravel were usually found in spawning areas which would have had fairly uniform hydraulic conditions without their presence. Dunes were generally found near the river margin or in association with islands, but were also present on some mid-channel gravel bars which were well used by spawning fall chinook.

The wave form of spawning dunes in the Deschutes River ranges from two to eight feet in amplitude and 20 to 60 feet in periodicity. Two to five dunes typically occur in series within a particular spawning area, although a few series containing more parallel bands of spawning gravel than this were found in the river. Because these spawning dunes are an important feature of many prime spawning areas for fall chinook in the Deschutes, the value or implications of their presence in these areas was investigated. This results of this investigation indicate that these structures are usually a desirable component of prime spawning areas for salmonids.

Dunes are constructed by salmonids, typically fall chinook salmon, spawning in close proximity to one another year after year. This phenomenon, although not widely reported, has been observed in many rivers in the Pacific Northwest, northern California, British Columbia and Alaska. Chinook salmon construct and maintain persistent dunes in the Sacramento River near Redding, California (K. Buer, California Dept. Water Resources, Red Bluff, CA., pers. comm.) , and at Aleck Riffle on the Feather River, California (K. Buer, pers. comm.; D. Painter, Cal. Dept. Fish and Game, Oroville, CA. pers. comm.). Dunes in these systems have amplitudes of 2-5 ft and a periodicity of 20-50 ft.

Figure 15 is a photograph of dunes extending across the entire river channel of the Feather River, California at

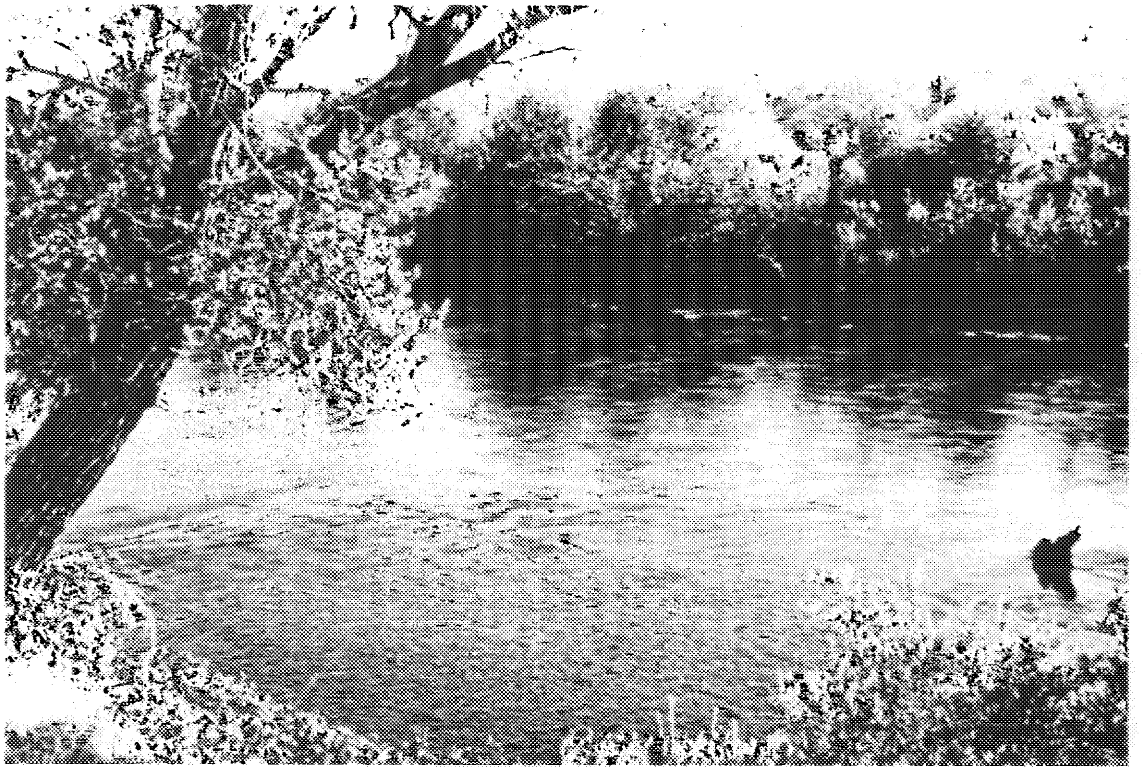


Figure 15. Chinook spawning dunes at Aleck Riffle, Feather River, California (photo from Buell & Associates files).

the Aleck Riffle taken in 1984. Spawning dunes built by chinook appear in the Wenatchee River near Leavenworth, Washington (James Mullan, USFWS, Leavenworth, WA, pers. comm.). William Platts (USDA Forest Service, Boise, ID, pers. comm.) reports that large dunes once extended all the way across the Snake River, Idaho in certain areas, but have disappeared, probably as a result of depressed chinook runs.

Figure 16 shows a long series of chinook spawning dunes in the Morice River below Morice Lake, northern British Columbia, taken in April 1977. Similar areas exist in other rivers in the Fraser River system in British Columbia, including the Chilko River below Chilko Lake (near Lingfield Creek) and the Nechako River (D. Bustard, BCF&W, Victoria, BC, pers. comm.; B. Tutty, DFO, Nanaimo, BC, pers. comm.). In Alaska, both chinook and sockeye salmon construct persistent spawning dunes (D. Parkinson, Parkinson & Assoc., Arcata, CA, pers. comm.).

Spawning dunes are found most commonly in regulated rivers or in rivers downstream of large lakes. There are two apparent reasons for this. First, the hydrology of most

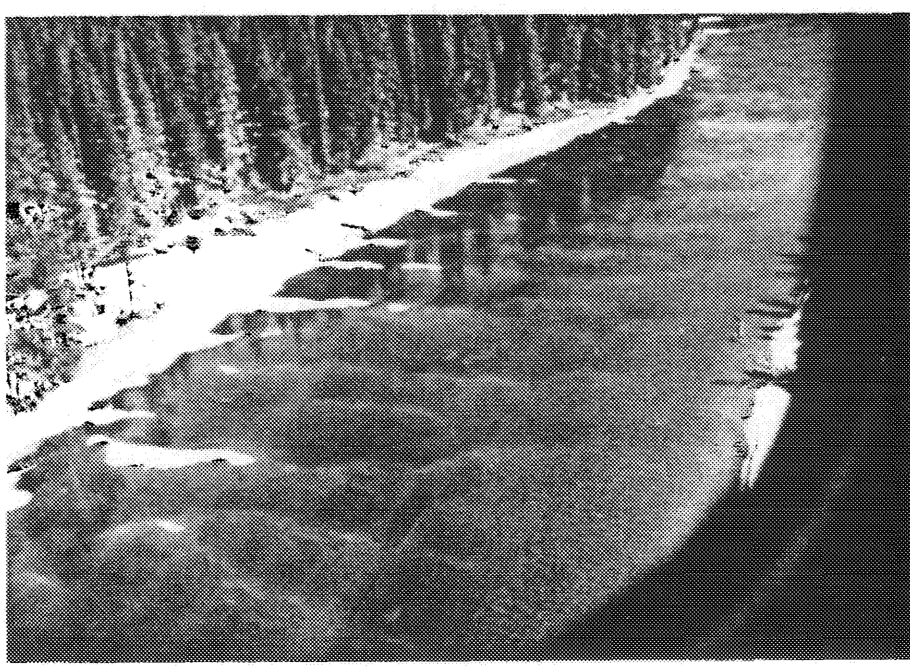


Figure 16. Extensive chinook spawning dunes in the Morice River below Morice Lake, northern British Columbia, April 1977 (source: G.D. Taylor, Fish and Wildlife Branch, Ministry of Environment, Victoria, BC),

regulated rivers and those below large natural lakes typically lacks pronounced peak flows which would tend to remove dune crests and fill-in troughs each year. Second, regulated rivers and those immediately below large lakes typically have limited bedload recruitment of gravels which would tend to physically prevent the progressive build-up of spawning dunes.

The physical characteristics of most spawning dunes make them desirable features of salmonid spawning areas. Unless they become too pronounced or too coarse, these structures can afford fish excellent conditions for redd digging and egg survival. The head differential from crest to crest may increase downwelling of water through the gravel to a greater degree-than a single redd would. Hydaulics for redd digging and egg deposition are improved adjacent to an existing redd or at the end of a spawning dune, causing initial dune formation and the lengthening of these structures over time.

Fish use the leading (upstream) edges of the dune crests for spawning, finding resting or holding conditions favorable in the troughs. This causes individual dunes to "migrate" downstream in a particular area over time. Older dune series can develop undesirable contours and be abandoned by spawners if fresh bedload is not delivered to the series periodically. Spawning materials can eventually become too coarse and the dunes too pronounced for the fish to use them. A similar phenomenon has been observed in the Feather River, California, where the development of undesirable dune contours led to the abandonment of a particularly large spawning dune below Oroville Dam (D. Painter, pers. comm.).

Spawning dunes are generally associated with areas heavily used or once heavily used by spawners. However, they do not necessarily indicate that redd superimposition is occuring. On the contrary, they in some cases may indicate optimum utilization of available spawning habitat. For example, dune structures in the Feather River, California below Oroville Dam lose their characteristic appearance when spawner densities exceed the capacity of spawning areas there (D. Painter, pers. comm.).

Although not strictly within the scope of this study, riverbed contours and substrate characteristics were documented for two prime spawning areas in Section I which contain spawning dunes. Measurements of water depth and substrate particle size were taken along transects parallel to water flow (perpendicular to the long axis of dunes) at "Disney" (RM 98.9) and at "Valve" (RM 99.6). This was done to document dune characteristics in this portion of the river in the event that certain measures to enhance these or similar structures are undertaken (see Conclusions and Recommendations section of this report).

Transverse profiles of spawning dunes at "Disney" and at "Valve" are presented in Figures 17 and 18 respectively for individuals unfamiliar with their physical appearance. Regular changes in substrate particle size along the transects are displayed graphically in the figure by rows of closed circles along the bottom of each profile.

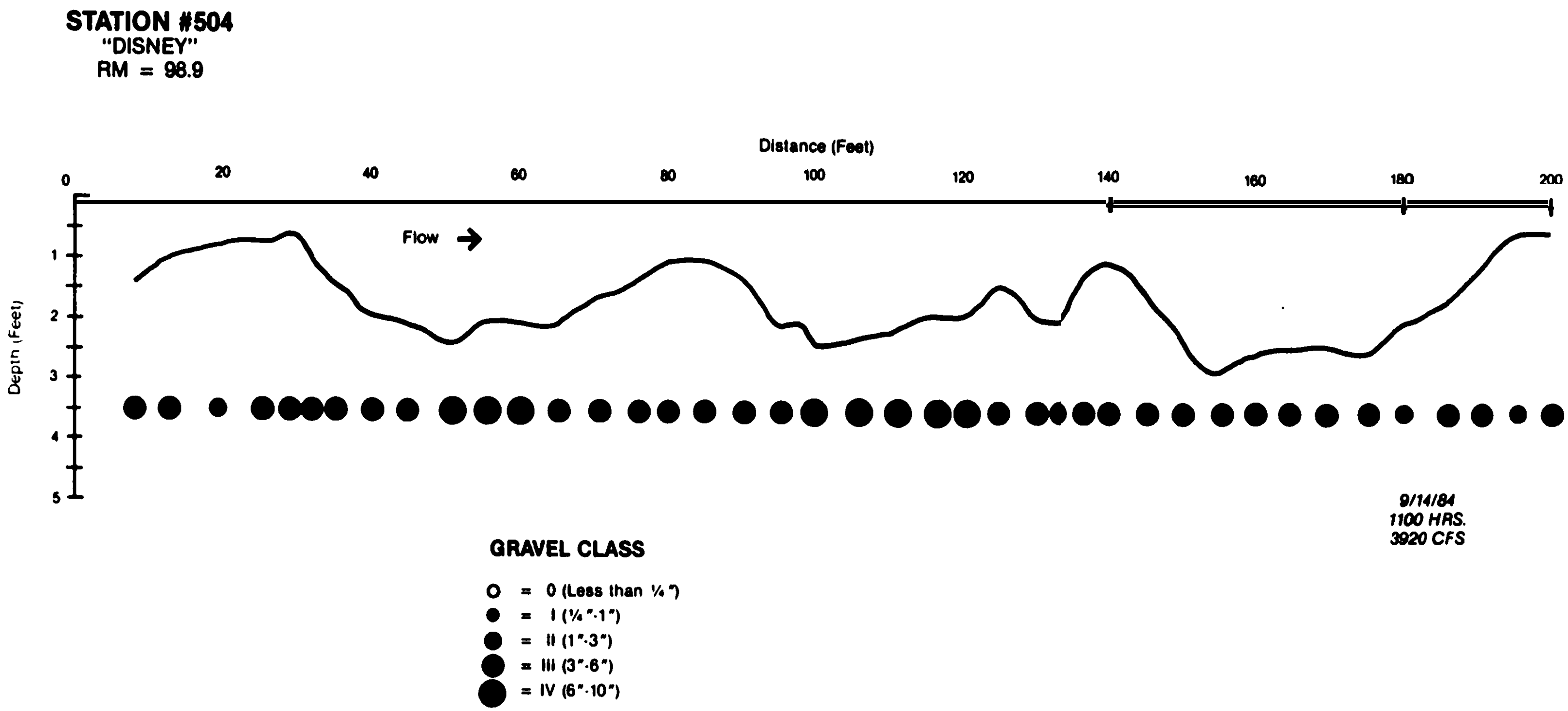


Figure 17. Transverse profiles of chinook spawning dunes at "Disney" (Section I; Station 504; RM 98.9).

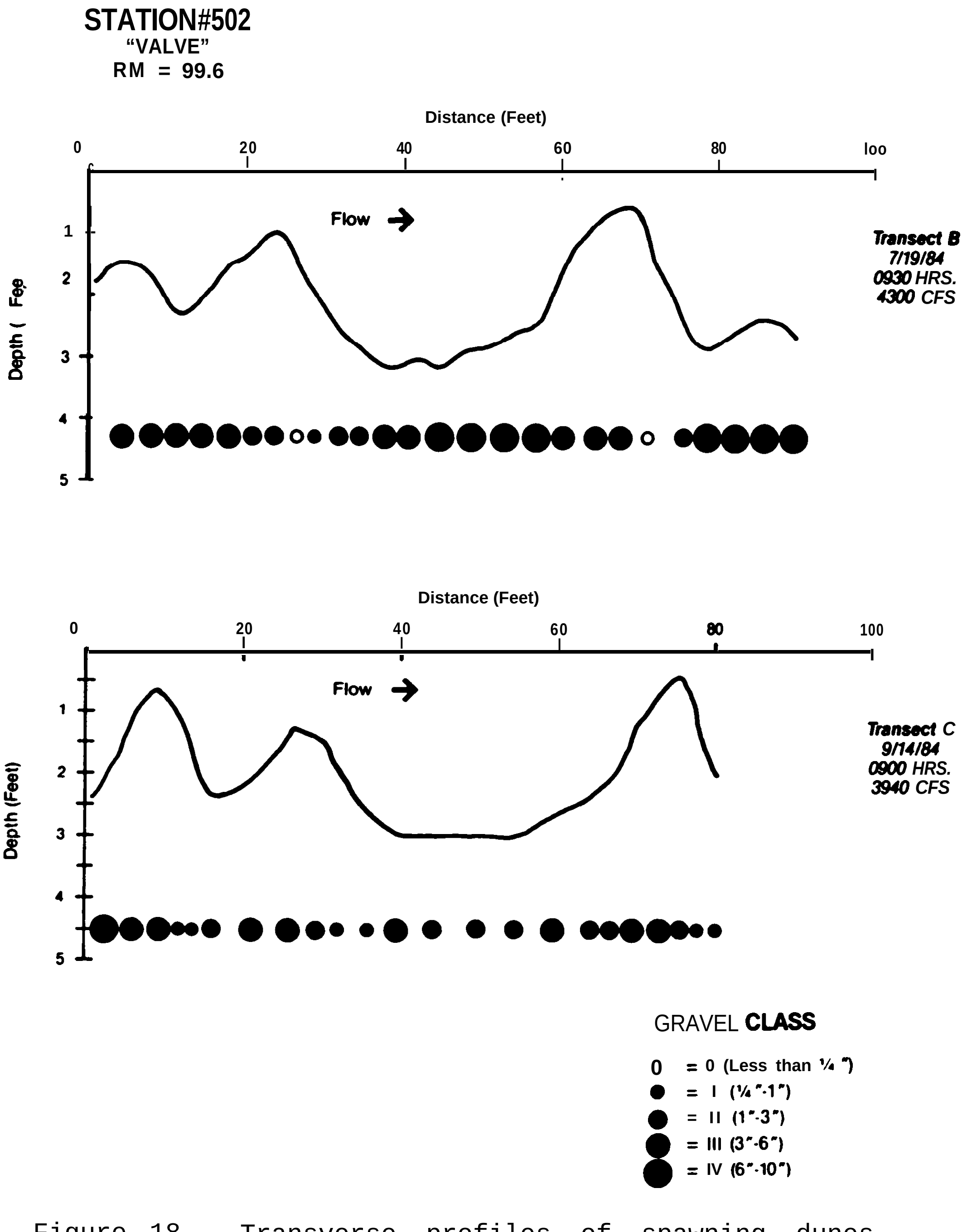


Figure 18. Transverse profiles of spawning dunes at "Valve" (Section I; Station 502; RM 99.6).

GRAVEL OUALITY - PERMEABILITY

The compaction, armoring or coarse subsurface strata of many spawning bars sampled during this study made it difficult to drive standpipes into the riverbed. In a number of instances the angle at which the standpipe penetrated the gravel bar changed repeatedly as it was driven into the gravel. This was due to deflection of the standpipe by large subsurface bed materials. In fact, it was sometimes felt that the disturbance caused by driving standpipes into compacted or poorly sorted bed materials led to high permeability readings which were not reflective of subgravel conditions prior to standpipe penetration.

Chinook redds and redd digging activities were often observed in the same areas from which the permeability measurements were taken. Female fall chinook salmon were frequently observed excavating redds in.areas with relatively high water velocities, apparently taking advantage of greater hydraulic forces as an assist in' spawning in compacted gravels.

Drawing firm conclusions from the permeability readings taken during this study was difficult. The permeability data collected are highly variable and were sometimes influenced by standpipe disturbance of the riverbed. For this reason the permeability readings should be looked upon only as relative indices of gravel quality and not as indicators of survival rates for salmon and trout embryos.

Results of the permeability sampling, including back transformed mean gravel permeabilities with 95% confidence limits for each sampling station and Study Section are summarized in Table 6. Individual permeability readings and specific information on the location and physical characteristics of each point sampled at the 23 stations are given in Appendix XI.

Observed gravel permeabilities were generally highest at the stations sampled in Section I (mean=1470 cm/hr; n=lOO) and lowest at those in Section IV (mean=318 cm/hr; n=120). However, it should be noted that some of the most permeable gravel sampled during this study was found in heavily used chinook spawning areas within Section IV (i.e. stations 102

Table 6. Back-transformed mean gravel permeabilities (cm/hr) with 95% confidence limits for areas in the lower Deschutes River, Oregon sampled with a Mark VI groundwater standpipe (Terhune 1958) in Fall 1983.

Study Section	Station	Sample Size	Permeabiltity cm/hr)	95% Confidence Limits Lower	Upper
I	501	20	1565.5	961.9	2547.6
	502	20	1874.6	1140.3	3081.5
	504	20	968.3	523.0	1792.3
	507A	20	1660.4	999.6	2757.4
	508A	20	1427.1	827.0	2462.2
	ALL	100	1465.4	1169.2	1836.8
II	II-5	20	1882.9	1528.4	2319.6
	10	20	118.9	72.0	196.0
	10A	20	254.7	137.3	471.7
	11	20	1563.6	1166.8	2095.2
	19	20	219.7	60.7	787.9
	ALL	100	457.1	317.3	658.4
III	47	20	977.9	460.9	2073.9
	56	20	490.4	345.2	696.4
	58A	20	801.5	463.8	1384.5
	58B	20	495.6	184.0	1332.1
	58C	20	1358.4	747.8	2466.8
	62	20	181.5	103.1	319.0
	92	20	1668.0	1106.0	2515.4
	ALL	140	696.3	542.5	893.8
IV	102	20	2094.4	1196.5	3665.5
	104	20	250.5	117.9	530.8
	114	20	112.4	52.0	241.6
	122	20	307.6	151.7	622.7
	123	20	24.3	6.2	88.1
	123A	20	2237.8	1048.0	4777.1
	ALL	120	318.1	208.6	486.7
ALL	ALL	460	609.2	514.4	721.4

and 123A). Mean gravel permeabilities for sections II (457 cm/hr; n=100) and III (696 cm/hr; n=140) fall between those for sections I and XV.

The observed pattern of relatively higher gravel permeability immediately below Pelton Reregulation Dam, and relatively lower gravel permeability dwonstream, particularly below White River, was also noted by the OSGC in the mid 1960%. This pattern may reflect limited transport of fine sediment into Section I and heavy sediment loads contributed to the lower Deschutes by White River and certain other tributaries. However, gravel permeabilities measured in the four study sections were so highly variable within and among the stations sampled, that observed differences between the study sections are not statistically significant ($p<0.10$). A summary of the ANOVA performed on log transformations of the permeability measurements made in Fall 1983 is presented in Table 7. Differences in permeability between the stations within the four Study Sections are highly significant ($p<0.001$).

A _priori_ hypotheses of gravel permeability differences between specific groupings of study sections were

Table 7. Analysis of Variance of log transformations of gravel permeability measurements taken at 23 stations within four Study Sections of the lower Deschutes River, Oregon during Fall 1983.

Source of Variation	df	MS	F	Signif.
Among Study Sections	3	46.0712	1.77a	N.S.
Section I vs. Sections 11,111 & IV	1	102.1818	3.93a	N.S.
Section IV vs. Sections II & III	1	25.8631	l.00a	N.S.
Section II vs. Section III	1	10.3430	0.40a	N.S.
Among Sections within Sections	19	25.9905	12.18	<O.OOl
Within Stations	437	2.1330		
Total	459	3.4078		

[a] MS_{Amon} Stations within Sections used as the denominator in F-ratio.

rejected. Measured permeabilities were not significantly different ($p<0.10$) between Study Section I and the other three sections; between Study Section IV and sections II and III; or between sections II and III.

Nine of the gravel bars (stations) sampled during this study were also sampled in the fall during the 1960% by the OSGC. A summary of the permeability data collected at these stations by the OSGC is presented in Table 8.

Results of the ANOVA performed on the permeability data collected at the one "matched-up" station in Section I are summarized in Table 9. A significant effect ($p<0.10$) of year on gravel permeability at the station (501) was detected. Gravel permeability was significantly ($p<0.10$) higher in 1965 than in 1964. This may reflect mobilization and cleansing of Section I gravels by the 1964 flood. The data do not show a significant difference between the permeabilities recorded at the station in the mid-1960% and those measured in 1983 ($p<0.10$).

Results of the two-way ANOVA for permeability data from the "matched-up" stations in Sections II, III and IV are

Table 8. Back-transformed mean gravel permeabilities (cm/hr) with 95% confidence limits for match-up stations sampled by the OSGC in the fall, 1963-1965.

Study Section	Station	Year	Sample Size	Mean Gravel Permeability cm/yr)	95 Percent Conf. Limits Lower	Upper
I	501	1964	9	421	52	3334
		1965	10	2096	866	5072
II	10	1963	24	79	28	224
		1964	10	121	21	66
	19	1963	14	78	15	398
		1964	11	46	4	409
III	47	1963	20	928	426	2020
		1964	11	551	129	2342
	58A	1963	16	486	170	1390
		1964	18	250	71	870
	58B	1963	20	134	37	483
		1964	10	152	51	451
IV	114	1963	28	112	46	273
		1964	8	194	101	374
	122	1963	17	83	17	390
		1964	8	39	4	311
	123	1963	13	529	244	1146
		1964	9	272	207	357

Table 9. One-way ANOVA for log transformations of permeability measurements taken in the Fall at station 501 (Study Section I), during 1964, 1965 and 1983. The results of special a *priori* contrasts of station means are given.

Source of Variation	df	SS	MS	F Ratio	Significance
Year	2	14.3131	7.1565	2.80	<0.05
1964 & 1965 vs 1983	1	2.5298	2.5298	0.99	N.S.
1964 v. 1965	1	12.1816	12.1816	4.76	<0.05
Error	36	92.1466	2.5596		
Total	38	106.4597			

presented in Table 10. No significant overall year effect on gravel permeability was detected for these stations ($p<0.10$). However, measured permeabilities varied significantly between stations ($p<0.001$). Measured differences between stations were not consistent between years. Interaction between the effects of year and station on measured permeability was highly significant ($p<0.01$). This station-year interaction is depicted graphically in Figure 19.

Based upon the results of multiple comparison tests (Tukey's HSD), the data show only that the measured gravel permeabilities differ significantly between study periods for one of the eight "matched-up" stations. Gravel permeability was significantly lower at station 123 in Section IV during 1983 than it was in 1963 and 1964 ($p<0.05$; Tukey's HSD).

Given the within-station variability of the permeability data collected (gravel permeabilities are plotted in <u>log scale</u> in Figure 19), only very dramatic changes in the permeability of gravel bars in the lower Deschutes would be shown significant in any statistical analysis. Changes of

Table 10. Two-way ANOVA for log transformations of permeability measurements taken in the Fall at eight stations in Study Sections II, III and IV during 1963, 1964 and 1983.

Source of Variation	df	SS	MS	F Ratio	Significance
Year	2	10.8724	5.4362	1.18	N.S.
Station	7	198.0821	28.2974	6.13	<0.001
Year x Sta.	14	155.5151	11.1082	2.41	<0.01
Error	373	1720.7715	4.6133		
Total	396	2116.6645			

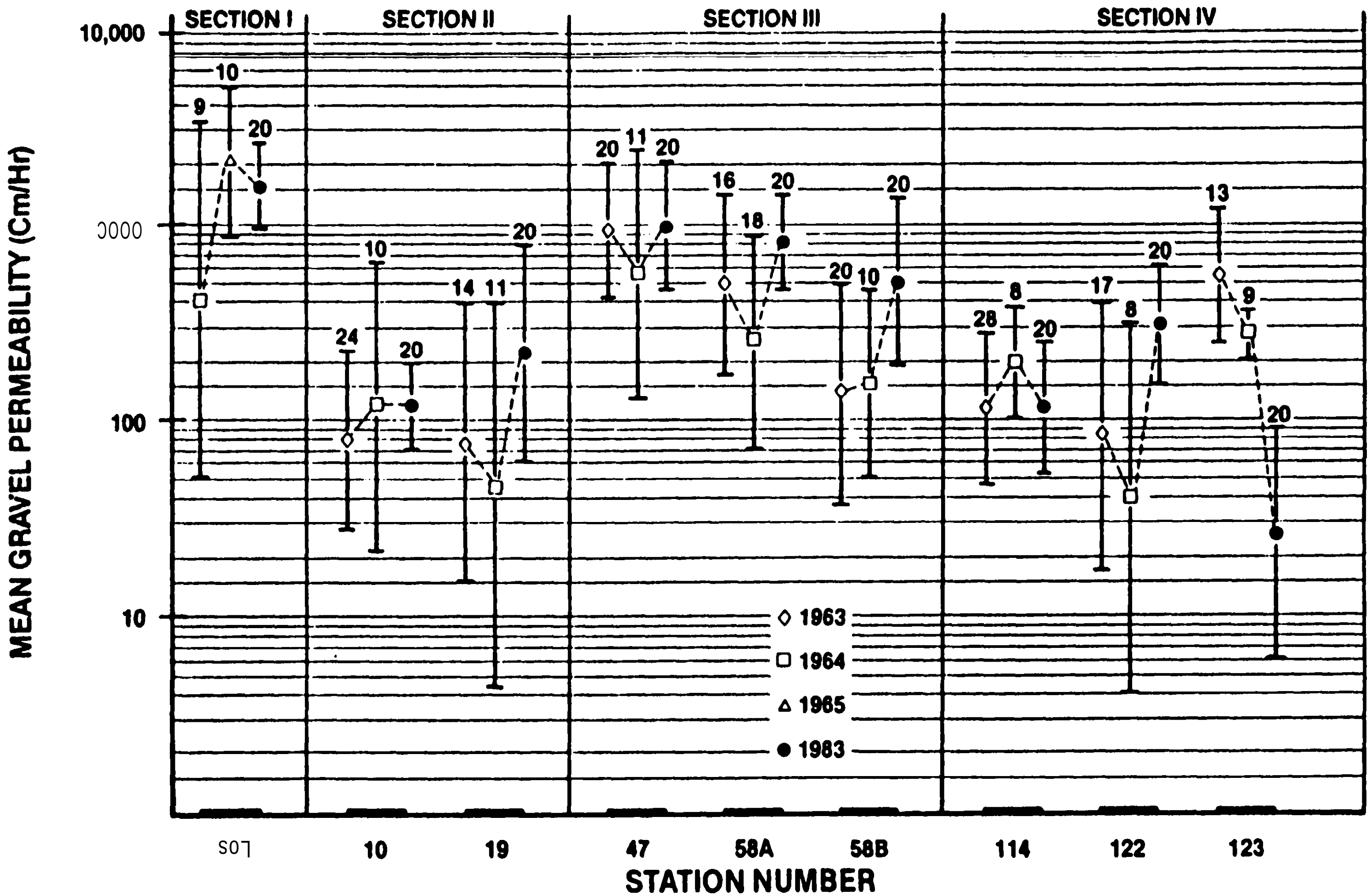


Figure 19. Means with 95 Percent Confidence Intervals for Permeability Readings Taken at Nine Lower Deschutes River, Oregon Stations in the Fall Both Before and After Completion of the Pelton/Round Butte Hydroproject. Sample Sizes are Given.

this magnitude have apparently not taken place in the Deschutes. However, actual long-term changes in gravel permeability may have been masked by: 1) natural variations in gravel permeability at individual gravel bars; and 2) differences in the magnitudes of flushing flows affecting gravel permeabilities during the years sampled.

The OSGC's fall permeability sampling was conducted during an extended period of low Deschutes River flows caused by the filling of Round Butte Reservoir and relatively dry weather. These flows would have tended to reduce gravel permeability by allowing an accumulation of fine sediment and organic material in the stream bed. In contrast, Deschutes flows recorded in the winter, spring and early summer of 1983 were relatively high and probably removed accumulated fine material from the streambed. In fact, streamflows at Pelton gage in Spring 1983 were the highest spring flows recorded since the PGE hydrocomplex was completed.

GRAVEL COMPOSITION

Freeze core sampling proved to be very difficult in many of the chinook and trout spawning areas sampled. As with the permeability sampling conducted, problems frequently arose when field personnel drove the sampling apparatus into the riverbed. Freezing tubes were often bent as they penetrated the gravel being sampled, even in a few areas where surface gravels were relatively small and well sorted. The reason for this was that many gravel bars in the Deschutes have compacted surface gravels: others can have a relatively thin surface layer of loose, well sorted gravel overlaying densely compacted subsurface gravels.

Chinook

A total of 99 stratified gravel samples, each composed of four 101.6 mm (4 in) thick depth strata, were collected in Fall 1983 at 10 sampling stations established in areas considered suitable for fall chinook spawning. Ten stratified samples were collected at all but one of the stations. Nine samples were collected at Station 10-A due to equipment failure.

Two sets of gravel quality parameters, one with and one without 101.6-127 mm (4-5 in) diameter rocks considered are given in Appendix XII. Each of these sets includes a geometric mean particle diameter, sorting coefficient, percentage by weight of particles less than 2.38 mm (0.09 in) in diameter, and Fredle index for each depth subsample of gravel collected at chinook spawning areas. Parameters based upon all sediment particles less than 127 mm in diameter (excluding any particle greater than 127 mm in diameter) within each subsample were used in the analysis of gravel quality presented here.

Appendix XIII presents mean values and variability of each gravel quality parameter for each depth sampled at each chinook spawning area studied in 1983. Gravel between 101.6 and 127 mm in diameter was present in approximately 10 percent of the depth subsamples of gravel, and nearly 25 percent of the samples collected. The percentages would have been even higher if sampling of some of the coarser spawning gravels frequently used by fall chinook in the Deschutes had been possible.

Fredle indices calculated for each of the upper three depth strata for each gravel sample collected were log-transformed and used to test for significant gravel quality differences between the study sections using ANOVA. Fredle indices for the deepest depth stratum sampled at each station (30-40 cm) were excluded from the analysis because salmon generally deposit their eggs within the upper 30 cm of gravel. The hypotheses tested and results of the statistical analysis are summarized in Table 11.

Based upon Fredle indices, chinook gravel quality differed significantly ($p<0.001$) both among study sections and between depth strata. However, significant interaction ($p<0.05$) between the Study Section and the depth strata factors indicates that differences between sections are not consistent between depth strata. This interaction has at least two likely sources. First, it was difficult to extract frozen cores of chinook spawning gravel at a number of the ten stations sampled. Subsamples of the upper 101.6cm (4 in) of gravel at those stations sometimes disintegrated when extracted because of the presence of a very coarse "armor" layer. Since variation in the difficulty of sampling of the upper stratum of gravels at

Table 11. Analysis of Variance[a] of log transformed Fredle indices for depth stratified samples of chinook spawning gravel collected in 1983 at 10 stations in the lower Deschutes River, Oregon. Stations were selected to represent the condition of gravel suitable for fall chinook spawning with each of four Study Sections.

Source of Variation	df	MS	F	Signif.
Among Study Sections	3	8.4884	25.81[d]	<0.001
Among Stations within Sections	6	0.3289[b]	1.13	N.S.
Among Depth Strata	2	14.9026	63.81[e]	<0.001
Sections x Depth Strata	6	0.9133	3.91[e]	<0.05
Depth Strat x Stations w/in Sects.	12	0.2336[c]	0.80	
Within Stations	267	0.2903		
Total	296	0.4685		

(CONTINUED, SEE NEXT PAGE)

a Refer to p. 359-366 in Winer (1971) for an explanation of statistical designs involving both nested and crossed factors (effects).

b MS_{Among} Stations within Sections.

c MS_{Depth} Strata x Stations within Sections.

d "b" used as denominator in F-ratio.

e "C" used as denominator in F-ratio.

Table 11, continued.

Apriori Tests of Orthogonal Study Section Effects for Each Depth Stratum:

Source of Variation	df	MS	E	Signif.
Upper Stratum (0-10cm):				
Among Sections	3	6.2974	19.15	<0.01
Section 1 vs Sections II,III,IV	1	0.9453	2.87	N.S.
Sections IV vs Sections II & III	1	8.4881	25.81	<0.01
Section II vs Section III	1	4.9374	15.01	<0.05
Middle Stratum (10-20 cm):				
Among Sections	3	1.9633	5.97	CO.05
Section I vs Sections II,III,IV	1	0.0463	0.14	N.S.
Section IV vs Sections II & III	1	5.5398	17.15	<0.01
Section II vs Section III	1	0.0220	0.07	N.S.
Lower Stratum (20-30 cm):				
Among Sections	3	2.0542	6.25	<0.05
Section I vs Sections II,III,IV	1	0.0186	0.06	N.S.
Section IV vs Sections II & III	1	5.5966	18.23	<0.01
Section II vs Section III	1	0.0045	0.01	N.S.

stations may have been independent of subsurface gravel quality, this could be responsible for the interaction. Secondly, the interaction may indicate that actual gravel quality differences between the study sections varied with depth.

Fredle indices for chinook spawning gravel collected at stations in Section I do not differ significantly from those of gravel sampled at stations in the other three study sections for either the upper, middle, or lower depth stratum. Fredle indices for gravel collected at stations in Section IV, below White River, were higher than those for gravel collected at stations in sections II and III. The difference was significant ($p<0.01$) for each of the three sample depths. This result is somewhat surprising since gravel quality and the survival rate for incubating salmonid alevins were thought by many biologists to be poor below White River. It is suspected that the overall gravel quality in Section IV is generally lower than elsewhere in the river, although quite good in those areas heavily used by spawning fish. Both stations sampled in Section IV are well used by chinook spawners at the present time.

Fish clean gravel quite effectively when spawning and may maintain or improve gravel quality through repeated use. Spawning dunes present in certain areas of the Deschutes are indications that chinook are certainly capable of significantly changing the contours of gravel bars in the river, and probably the composition of the bars as well.

Fredle indices for the upper stratum of gravel at stations sampled in Section II were significantly higher than those for Section III ($p<0.05$). However, no significant difference was detected between Fredle indices for the middle and lower strata for the same sections. The difference in Fredle indices for the surface gravels from the two sections may reflect either lower gravel quality at the stations in Section III, or the presence of a coarse armor layer at stations in Section II. In either case, the Fredle indices for the subsamples of surface gravel from Section III are not so low as to indicate the existence of a gravel quality problem at the stations sampled.

Back-transformed mean Fredle indices for each depth stratum of chinook gravel are plotted against Study Section in Figure 20. The mean Fredle index for each Study Section

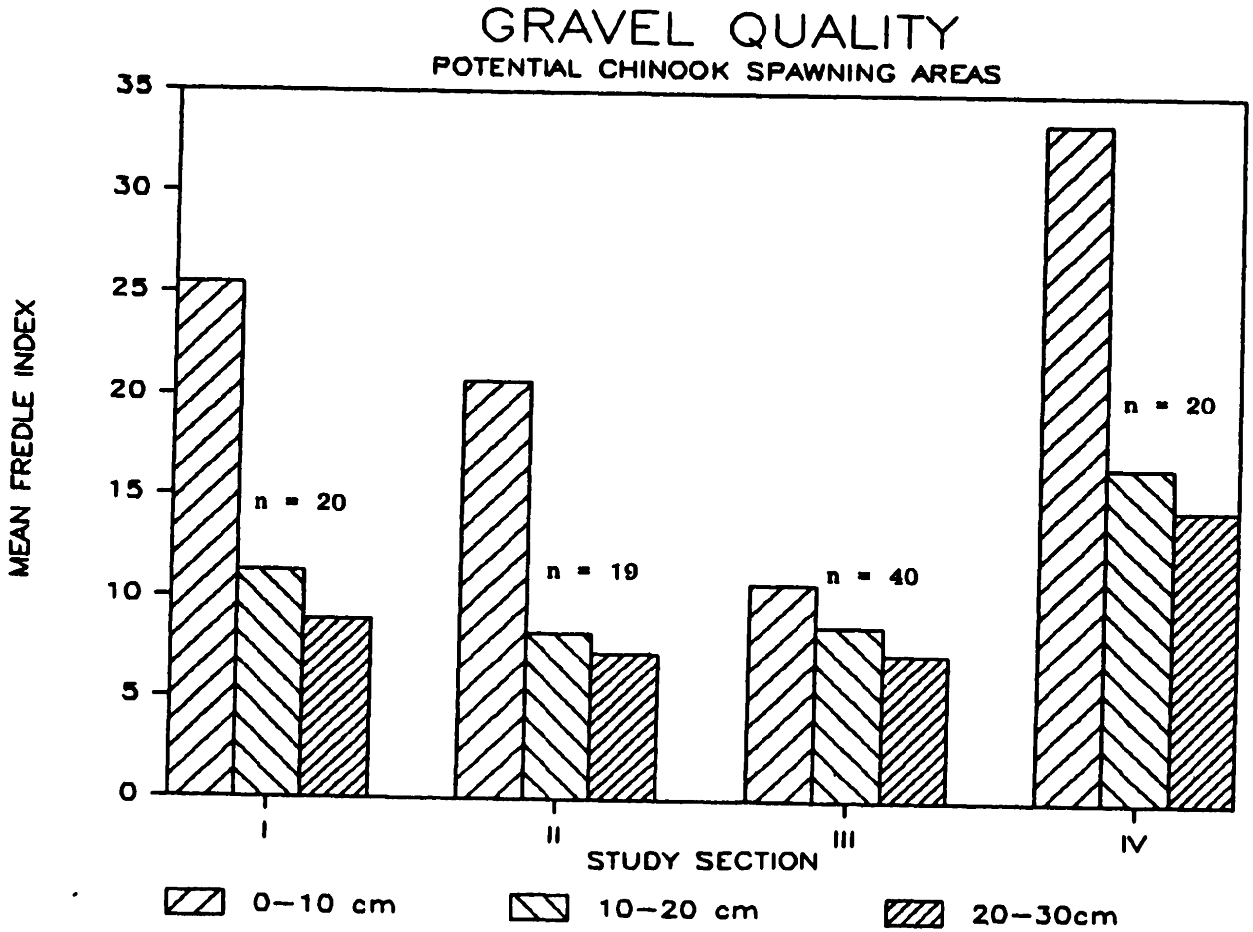


Figure 20. Back-transformed mean Fredle indices by depth for gravel samples collected at chinook spawning areas in each of four study sections of the lower Deschutes River, Oregon during Fall 1983.

declined with increasing stratum depth. On average, the depth stratum most likely to impede salmonid embryo survival-to-emergence at the stations in each Section was the deepest one considered, from 20-30 cm beneath the gravel surface. Back-calculated mean Fredle indices for this stratum were 8.89, 7.27, 7.34 and 14.59 for sections I, II, III and IV respectively. A Fredle index value of from five to seven generally reflects conditions conducive to high rates of survival for incubating salmonid embryos.

Back-transformed mean Fredle indices for each depth stratum at each station are presented with their 95 percent confidence limits in Table 12, and plotted by river mile in Figure 21. Table 12 also contains statistics on geometric mean particle sizes, sorting coefficients and percent fines (<2.38 mm in diameter).

Some authors have suggested that freeze-core sampling may not yiela adequately large samples in coarse substrates (Shirazi et al., 1981). While this study cannot address this question directly, it can be reported that it was often difficult to extract cores from areas of coarse gravel. The samples that were extracted from these areas

Table 12. Back-transformed mean Fredle indices with 95% confidence limits, average geometric means, mean sorting coefficients and percent fire sediments for each depth stratum of gravel at each cbiroot spawning area sampled at the lower Deschutes River, Oregon in 1983.

Study Sect.	Sta.	River Mile	Sample Depth (cm)	Sample Size	Geom. Mean	Sorting Coeff.	Percent Fines <2.38mm	Fredle Index Mean	95% Conf. Limits Upper	95% Conf. Limits Lower
I	501	99.9	0-10	10	46.17	1.53	1.23	27.85	17.77	43.34
			10-20	10	27.77	1.91	6.18	13.30	8.71	20.05
			20-30	10	24.47	2.13	8.88	10.15	6.35	16.61
	504	91.9	0-10	10	3B.32	1.59	2.55	23.39	16.49	33.01
			10-20	10	25.25	2.46	9.01	9.60	5.98	15.11
			20-30	10	20.14	2.36	11.92	1.55	4.23	12.91
II	5	96.1	0-10	10	36.12	1.90	1.89	18.28	12.09	21.36
			10-20	10	21.05	2.19	12.13	1.97	5.23	11.91
			20-30	10	23.61	2.30	12.56	9.12	1.95	16.23
	10A	91.1	o-10	9	10.10	1.56	3.90	23.83	14.61	31.93
			10-20	9	22.11	2.45	13.11	8.57	5.02	11.23
			20-30	9	15.86	2.14	16.91	5.61	3.82	8.07
III	47	71.2	0-10	10	21.22	1.83	1.15	14.58	10.12	19.53
			10-20	10	IB.tB	2.23	9.91	6.12	5.89	11.01
			20-30	10	18.16	2.15	9.99	8.26	5.95	11.35
	56	10.3	0-10	10	23.01	2.24	6.30	9.57	6.31	14.28
			10-20	10	23.34	2.11	10.88	10.16	5.15	17.43
			20-30	10	19.11	2.37	13.26	7.87	5.90	10.10
	62	65.7	0-10	10	23.58	2.49	12.10	9.11	5.66	14.37
			10-20	10	22.52	2.21	14.34	6.13	4.70	15.95
			20-30	10	11.19	2.46	15.25	6.64	3.96	10.71
	9 2	47.5	0-10	10	22.29	2.31	9.56	16.52	7.88	13.94
			10-20	10	19.26	2.3.	13.05	1.11	5.06	11.50
			20-30	10	16.40	2.41	15.51	6.70	3.92	11.05
IV	104	31.1	0-10	10	47.28	1.31	2.36	30.16	21.11	36.16
			10-20	10	24.57	1.69	9.45	14.02	9.15	20.01
			20-30	10	21.56	1.61	10.55	15.63	10.11	23.81
	123	10.2	0-10	10	53.64	1.31	1 55	37.40	21.15	50.29
			10-20	10	33.01	1.59	1.11	19.82	14.14	21.64
			20-30	10	21.13	1.77	12.99	13.91	9.13	20.95

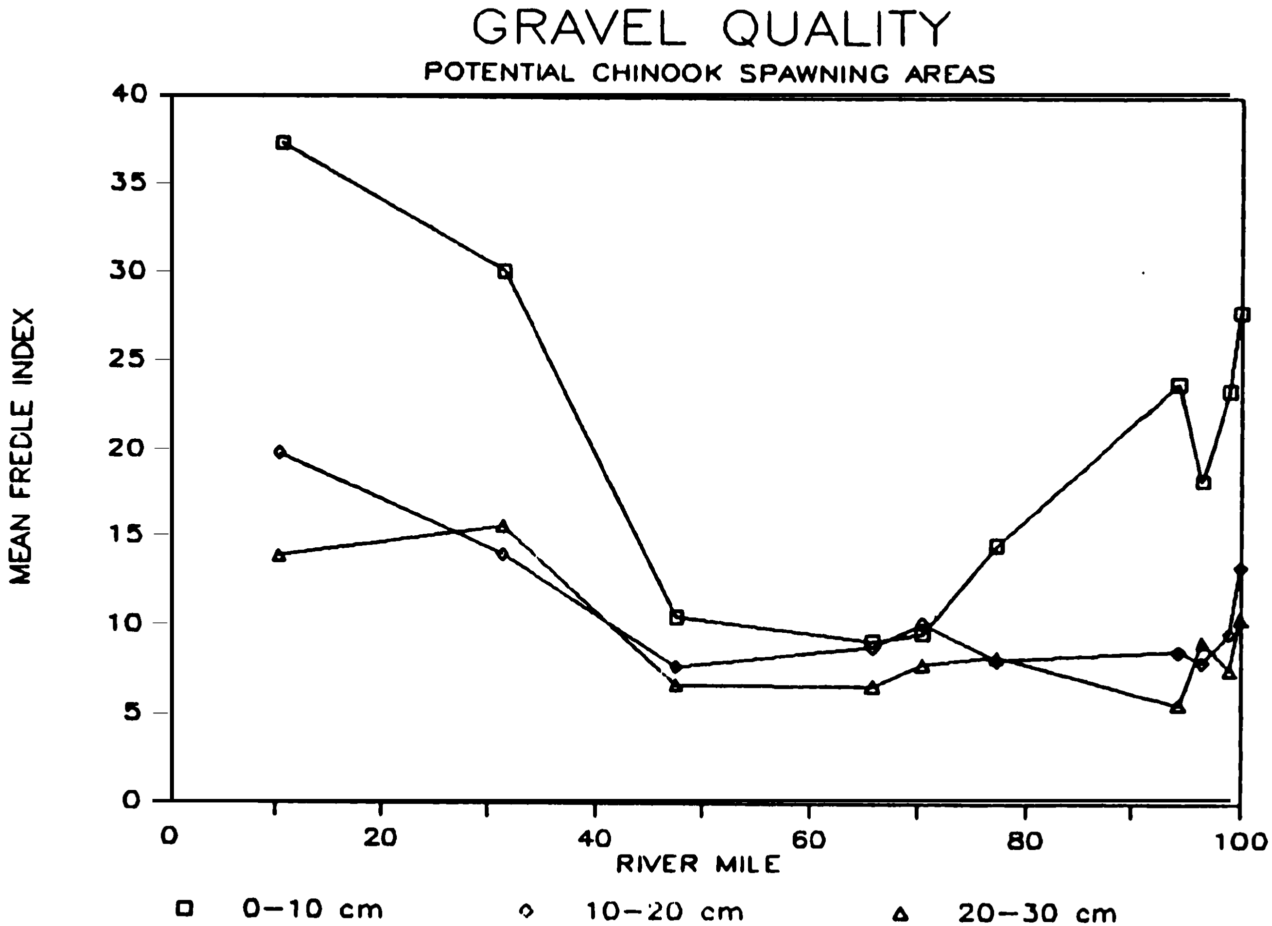


Figure 21. Back-transformed mean Fredle indices by stratum depth and river mile for gravel samples collected at chinook spawning areas in the lower Deschutes River, Oregon during Fall 1983.

were sometimes of marginal quality, particularly in the uppermost stratum, due to fragmentation or erosion of the upper part of the core as it was extracted. It should be noted, however, that in spite of its possible shortcomings, the freeze-core device is the only gravel sampler presently available that is capable of extracting stratified samples of chinook spawning gravel from a river like the Deschutes. Prevailing water depths at most chinook spawning areas in the river preclude the use of other types of gravel sampling equipment.

A number of laboratory experiments relating the survival rate of salmonid embryos to the sediment composition of the gravel in which they incubate have been conducted. Two studies (Lotspeich and Everest 1981; Tappel 1981) have led to the development of empirical relationships between Fredle indices and survival-to-emergence rates of salmonid fry. Neither of these-studies has addressed the question of what survival-to-emergence rates might be for fall chinook salmon in coarse gravel mixtures similar to those found in spawning areas on the Deschutes.

Tappel (1981) established a relationship between chinook survival to emergence and the Fredle index of incubation gravel, but used only gravel less than 2 inches in diameter during his experiments. His results were complicated by the use of chinook embryos that were at an advanced stage of development when placed in various gravel mixtures. This complication led to overestimated survival-to-emergence rates for the mixtures used. The degree of overestimation could not be quantified.

Lotspeich and Everest (1981) used the data of Phillips et al. (1975) to develop relationships between Fredle index values and the survival-to-emergence of coho salmon and steelhead trout. The relationships are depicted in Figure 22. Lotspeich and Everest (1981) postulated that steelhead survived at a greater rate than coho in gravel with the same Fredle index because the greater size of coho fry makes their emergence from gravel more difficult. Assuming that this postulation is correct, chinook salmon embryos would be expected to survive at an even lower rate than steelhead or coho salmon embryos when incubating in gravel of the same quality.

Shirazi and Seim (1981) have developed an embryo survival index for salmonid spawning gravel using experimental data

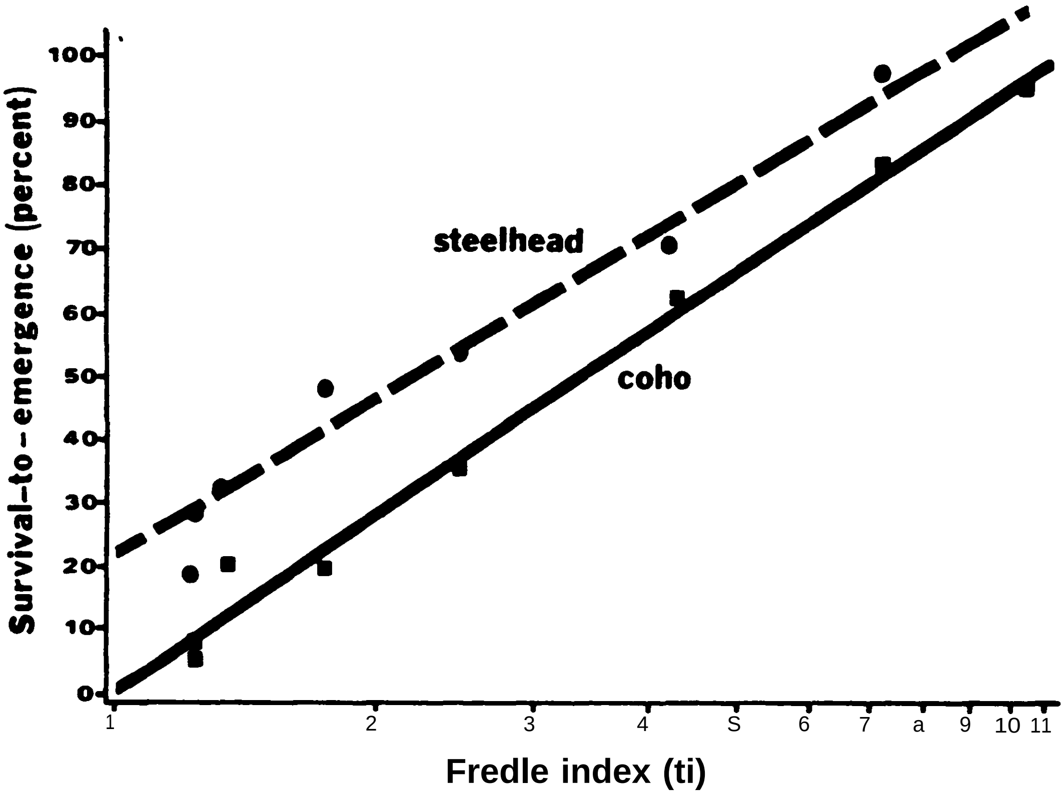


Figure 22. Relationship between Fredle index values and survival-to-emergence of coho salmon and steelhead trout (based on data of Phillips et al.1975).

collected by a number of researchers (Figure 23). Their index is the ratio of the geometric mean particle diameter and the average egg diameter of the species of interest (d_g/d_e). By incorporating the egg size of the particular fish species to be considered, this index attempts to account for differences in salmonid embryo survival which are thought to be at least partially due to size differences in embryos and emergent fry.

Of the available information on embryo survival rates for salmonids, it is felt that the quality index and survival relationships developed by Shirazi and Siem (1981) will give the best indication of survival-to-emergence rates for fall chinook embryos incubating in gravel bars of the Deschutes River. Their index and survival relationships were selected over those of other researchers because they: 1) are based upon experimental data not complicated by Tappel's (1981) problems of advanced embryo development; and 2) attempt to account for the large size of chinook embryos and emerging fry.

Results of laboratory studies of survival-to-emergence are not entirely applicable to natural conditions and have yet

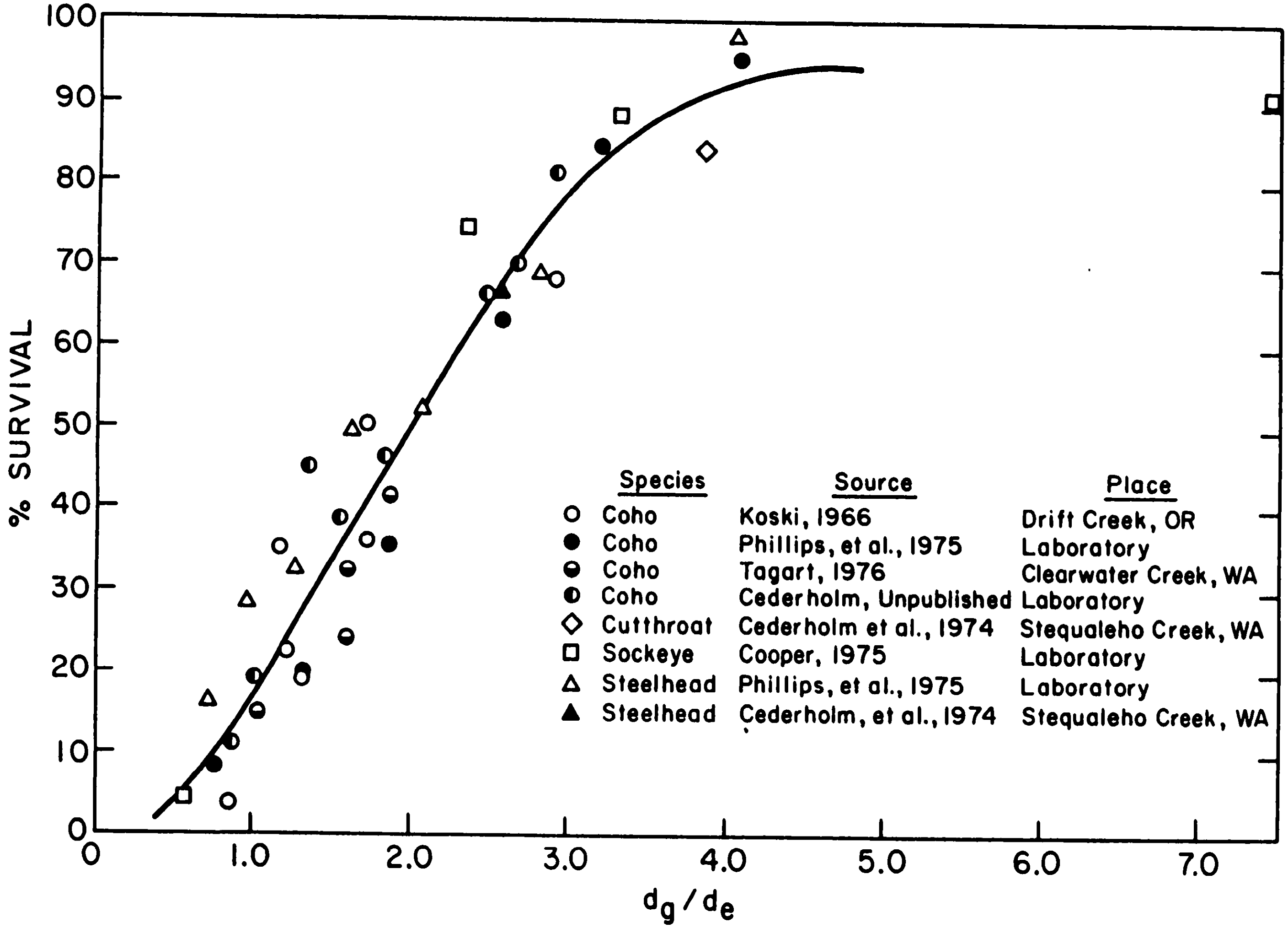


Figure 23. Relationship between the embryo survival index (d_g/d_e) and survival-to-emergence for salmon and trout (source: Shirazi and Seim 1981).

to be verified in the field. In most laboratory experiments, developing salmonid embryos and emerging salmonid fry are subjected to conditions which are more stable than those the embryos and fry would face in nature. Laboratory experiments may not account for the presence of organic materials in spawning areas which can slow rates of oxygen delivery and metabolic waste removal within redds. In addition, applying the results of these experiments to gravel conditions prior to redd construction could indicate lower survival rates than those actually experinced in a stream.

With the reservations given above, survival-to-emergence rates were predicted for fall chinook embryos incubating at the ten stations sampled (Table 13). The rate for each station was determined by taking the lowest survival rate of the three predicted by the mean "d_g/d_e" for the upper, middle and lower depth strata. This was done because most emerging fry would have to pass through all three depth strata during emergence in order to survive. The survival-to-emergence rate for most embryos or fry would thus be limited by conditions in the stratum having the poorest gravel quality.

Table 13. Survival index for the limiting depth stratum at of gravel at each of 10 potential chinook spawning areas sanpled at the lower Deschutes River, Oregon, Fall 1983.

study Section	Station	Sample Size	Limiting D	d_g/d_e	Survival Index[a]
I	501	10	20-30 an	3.8	90%
	504	10	20-30 an	3.1	80%
II	5	10	10-20 an	3.2	82%
	10A	9	20-3Oan	2.4	62%
III	47	10	20-30 an	2.8	75%
	56	10	20-30 an	3.0	80%
	62	10	20-30 an	2.8	75%
	92	10	20-30 cm	2.5	65%
IV	104	10	10-20 an	3.8	90%
	123	10	20-30 an	4.2	92%

d_g/d_e = (geometric mean particle diameter)/(mean egg diameter); de for fall chinook salmon and is approximately 6.5 mm (Scott and Crossman, 1973).

a - survival-to-emergence rates of chinook embryos predicted by relationships reported by Shirazi and Seim (1981).

The rates presented in Table 13 should be looked upon as relative indices and not as absolute predictors of embryo survival. The validity of applying these survival rates to fall chinook in the Deschutes is entirely dependent on the assumptions that: 1) the survival relationships developed by Shirazi and Seim (1981) are valid for chinook embryos; and 2) the quality index used (d_g/d_e) is a good indicator of gravel quality in fall chinook spawning areas.

Fredle indices calculated for gravel collected at a few of the stations sampled in Fall 1983 indicated considerably higher embryo survival than expected. At two such stations, Cedar Island (Section IV, Station 104; RM 31.1) and Windy Flat (Section III, Station 62; RM 65.2), visual inspection and gravel permeabilities suggested relatively low gravel quality where Fredle indices indicated relatively high gravel quality. We hypothesize two explanations for these conflicts:

- Some of the stations sampled had relatively angular gravel. However, the application of Fredle indices, which assumes that the packing relationships of spheres are approximated by spawning gravel, may not be entirely appropriate for areas having angular gravels. Other researchers have noted that gravels of apparently similar quality but differing angularity can have different permeabilities (Platts et al. 1979). Sediment particles which have flat surfaces may pack more tightly, and have less interstitial space for a given level of sedimentation, than more rounded sediment particles do.

- A number of the gravel samples collected from spawning areas in the Deshutes contained living and dead vegetation which was not accounted for in our gravimetric analyses due to oven drying of samples. This vegetion may clog gravel interstices and reduce intergravel flow.

Steelhead

Depth stratified core samples were collected as soon after completion of the emergence period for steelhead as possible. Geometric means, sorting coefficients, percent fines less than 2.38 mm in diameter, and Fredle indices were calculated based on the particle size distribution of each gravel subsample collected. Summaries of the gravel quality parameters calculated for each sample depth at each station are given in Appendix XIV. The values of each gravel quality parameter for each individual depth subsample of steelhead gravel collected during this study are given in Appendix XIV.

Fredle indices calculated for each of the three depth strata within each sample of steelhead gravel collected were log transformed. These transformed indices were then used to test for significant gravel quality differences between the Study Sections using ANOVA. The results of the statistical analyses are summarized in Table 14.

Based on Fredle indices, quality of gravel in the steelhead spawning areas did not differ significantly ($p<0.05$) between sections. However there was a highly significant difference ($p<0.001$) in gravel quality between depth strata. Highly significant ($p<0.001$) gravel quality differences between stations within the study sections were also detected.

Table 14. Analysis of Variance a of log transformed Fredle indices for depth stratified samples of steelhead spawning gravel collected in 1984 at 13 stations in the lower Deschutes River, Oregon. Stations were selected to represent the condition of gravel suitable for steelhead trout spawning within each of four Study Sections.

Source of Variation	df	MS	F	Signif.
Among Study Sections	3	2.3323	0.56[d]	N.S.
Section I vs Sections II,III,IV	1	2.0786	0.50[d]	N.S.
Section IV vs Section II & III	1	0.5950	0.14[d]	N.S.
Section II vs Section III	1	4.4574	1.07[d]	N.S.
Among Stations within Sections	9	4.1653[b]	15.73	<0 .00l
Among Depth Strata	2	11.6623	39.20[e]	<0.00l
Sections x Depth Strata	6	0.4267	1.43[e]	N.S.
Depth Strata x Stations w/in Sect.	18	0.2975[c]	1.12	N.S.
Within Stations	546	0.2648		
Total	584	0.3761		

a Refer to p.359-366 in Winer (1971) for an explanation of statistical designs involving both nested and crossed factors (effects).

b MS_{Among} Stations within Sections

c MS_{Depth} Strata x Stations within Sections

d "b" used as denominator in F-ratio

e "c" used as denominator in F-ratio

Back-transformed mean Fredle indices for each depth stratum of steelhead gravel are plotted against Study Section in Figure 24. Fredle indices calculated for subsamples of steelhead gravel collected in Section I were generally higher than those for the other three sections for each depth stratum. Mean Fredle indices for the three depth strata sampled at stations in Section III are greater than those for either Section II or Section IV.

As noted previously, the observed differences in mean Fredle indices between the four sections are not statistically significant. However, a reasonable explanation of this pattern can be constructed on the basis of tributary stream contributions of sediment and flow to each Study Section. Good gravel quality at steelhead spawning areas in Section I might be expected as flows in this section are generally clearer than those downstream due to settling of fine sediment in the hydroproject reservoirs. Gravel quality in Section III may be strongly influenced by the relatively. clear and stable flows of the Warm Springs River. Many tributary streams entering the Deschutes in sections II and IV reduce gravel quality in those reaches because they often contribute substantial quantities of fine sediment to the river.

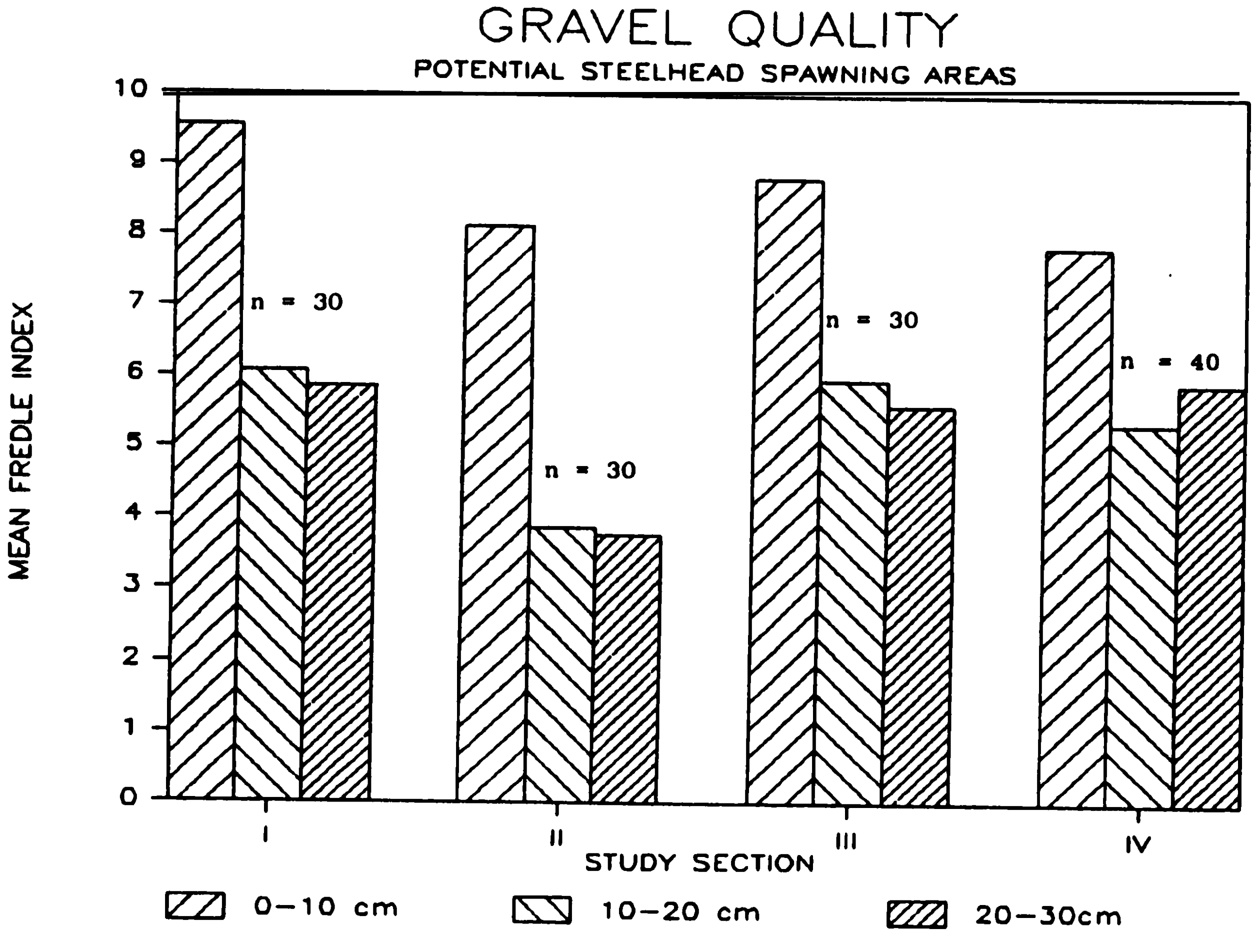


Figure 24. Back-transformed mean Fredle indices by depth for gravel samples collected at steelhead/ resident rainbow trout spawning areas in each of four study sections of the lower Deschutes River, Oregon during Summer 1984.

The mean Fredle index for each Study Section above White River declined with depth. In contrast, that for Section IV was, higher for the lower depth stratum than it was for the middle one. Although this apparent difference between sections is not statistically significant, it may well reflect the fact that deposits of finer gravel in Section IV tend to be thin, with subsurface layers of coarser or tightly compacted materials relatively close to the surface.

Table 15 gives the back-transformed mean Fredle index with 95% confidence limits, average geometric mean particle size, mean sorting coefficient, and mean percent fine sediment less than 2.38 millimeters in diameter for each depth stratum at each station sampled. The back-transformed mean Fredle index for each depth (stratum) of spawning gravel sampled at each station is plotted against river mile in Figure 25.

Survival-to-emergence indices for the limiting depth stratum of steelhead spawning gravel at each station are presented in Table 16. These indices are based on the

Table 15. Back-transformed mean Fredle indices with 95% confidence limits, average geometric means, mean sorting coefficients and percent fine sediments for each depth stratum of gravel at each steelhead sprraiag area sampled at the lower Deschutes River, Oregon daring 1964.

Study Sect.	Sta.	River Mile	Sample Depth (cm)	Sample Size	Geom. Mean	Sorting Coeff.	Per cent Fires <2.38mm	Fredle Index Mean	Fredle Index 35% Coaf. Limits Upper	Fredle Index 35% Coaf. Limits Lower
I	501	99.9	0-10	15	18.83	1.92	5.42	9.51	7.78	11.75
			10-20	15	18.91	2.44	11.17	7.36	5.25	10.20
			20-30	15	17.13	2.34	12.61	7.06	5.19	9.54
	504	96.9	0-10	15	20.60	2.04	6.27	10.47	7.93	13.75
			10-20	15	17.91	2.75	12.69	7.09	4.63	10.47
			20-30	15	17.64	2 26	12.69	7.31	5.32	9.94
	508A	98 0	0-10	15	18 65	2 04	8 83	6.60	5.72	12.94
			10-20	15	12.66	2.91	18.71	4.26	2.65	6.60
			20-30	15	12.02	3.04	19.46	3.77	2.55	5.40
II	11-5	96.4	0-10	15	16.82	1.61	6.66	10.54	9.02	12.30
			10-20	15	14.12	2.67	16.99	4.99	3.97	6.22
			20-30	15	14.99	2 90	16.17	5.06	3.56	1.04
	10	94 2	0-10	15	14.65	2.01	11.25	7.11	5.61	6.94
			10-20	15	13.67	2.93	16.46	4.67	3.14	6.15
			20-30	15	10.93	2 64	25.15	3.57	2.22	5.50
	615	86 7	0-10	15	15.39	2.09	12.22	7.15	5.42	9.34
			10-20	15	a.91	3.77	26.65	2 37	1.48	3.59
			20-30	15	10.27	3.43	25.59	2.67	1.90	4.17
III	56	69.2	0-10	15	19.00	1.74	7.30	10.15	7.58	13.46
			10-20	15	13.40	2.39	15.71	5.44	3.65	7.93
			20-30	15	12.36	2.63	19.10	4.70	2.63	7.50
	73	64.5	0-10	15	15.43	2.03	9.70	9.01	6.74	11.95
			10-20	15	16.04	2.50	14 05	6.26	5.07	7 73
			20-30	15	14.97	2.57	17.29	7.25	4.97	10.40
	630	61.8	0-10	15	16.70	1.79	9 15	7.45	5.12	9.63
			10-20	15	13.92	2.19	14.83	6.15	4.47	a.35
			20-30	15	17.60	2.30	14.44	5.36	3.43	6.14
IV	95	41 0	0-10	15	10 01	2.77	21.66	3.65	2.61	4.98
			10-20	15	9.05	3.56	26.29	2.63	1.16	3.72
			20-30	15	11.66	2.96	21.60	4.03	2.53	6.06

Table 15, Continued.

Study Sect.	Sta.	River Mile	Sample Depth (cm)	Sample Size	Geom. Mean	Sorting Coeff.	Percent Fines <2.38mm	Fredle Index Mean	95% Conf. Limits Upper	95% Conf. Limits Lower
IV	106	28 5	0-10	15	16 43	2.14	15.19	7.72	5.54	10.63
			10-20	15	16.02	2.36	16 72	7.04	5.25	9.36
			to-30	15	15.21	2.32	17.46	6.56	4.71	3.01
	109B	23.9	0-10	15	26.11	1.60	5.31	16.61	13.97	20.19
			10-20	15	20.55	2.04	11.63	9.78	7.68	12.39
			20-30	15	22.16	2.09	12.57	10.21	6.70	15.32
	113	21.9	0-10	15	16.94	2.31	12.69	7 44	5.01	10.74
			10-20	15	12.77	3.04	19.05	4.14	3 27	5.20
			20-30	15	13.11	3.03	19.62	1.31	2.93	6.26

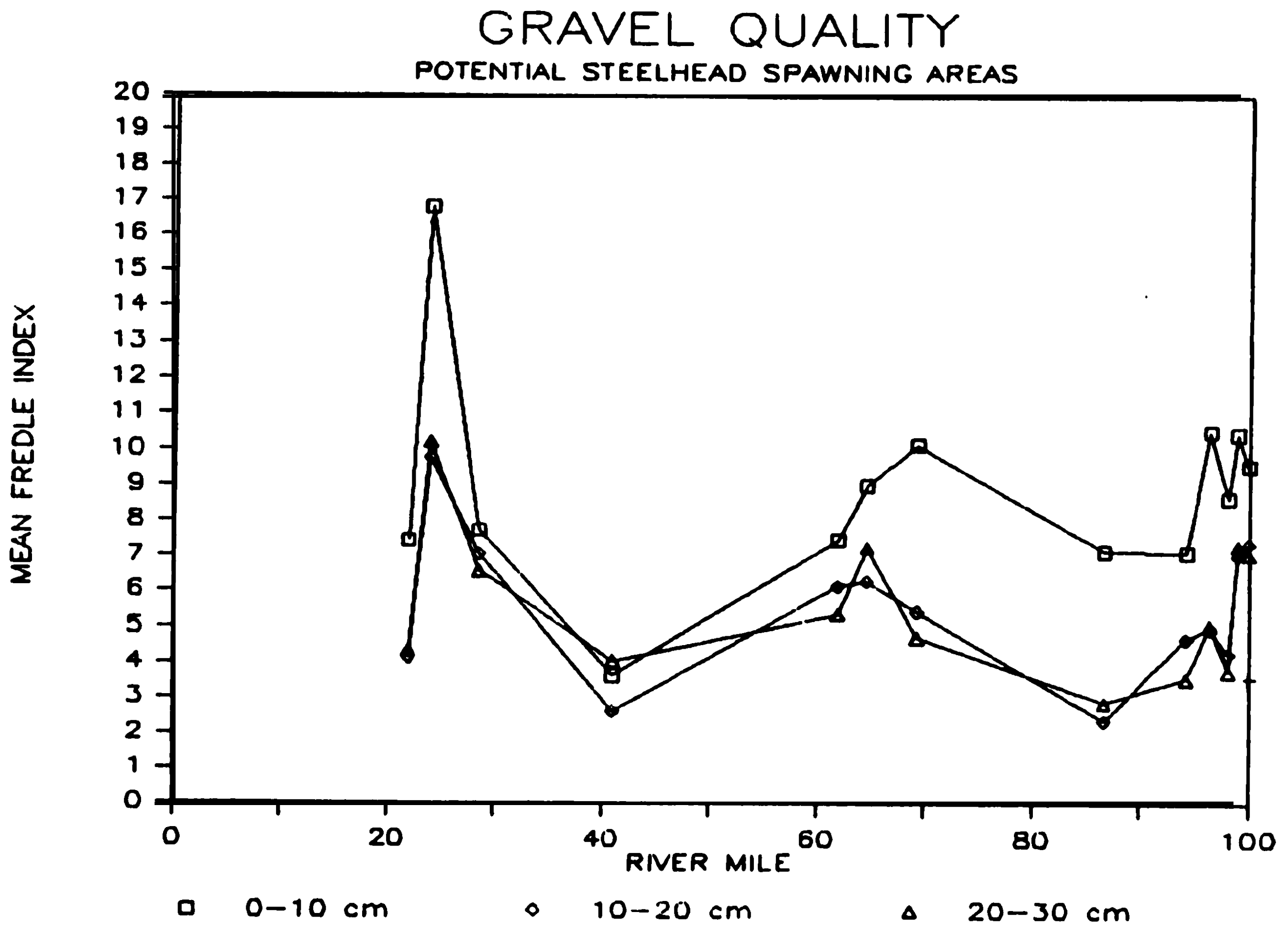


Figure 25. Back-transformed mean Fredle indices by stratum depth and river mile for gravel samples collected at steelhead/ resident rainbow trout spawning areas in the lower Deschutes River, Oregon during Summer 1984.

Table 16. Steelhead survival index for the limiting depth stratum at each steelhead spawning area sampled at the lower Deschutes River, Oregon in 1984.

Study Section	Station	Sample Size	Limiting Depth Stratum cm	Mean Fredle	Steelhead* Survival Index
I	501	15	20-30	7.08	95%
	504	15	10-20	7.04	95%
	508	15	20-30	3.77	70%
II	5	15	10-20	4.99	80%
	10	15	20-30	3.57	65%
	615	15	10-20	2.37	50%
III	58	15	20-30	4.70	75%
	73	15	10-20	6.28	90%
	630	15	20-30	5.36	85%
IV	95	15	10-20	2.63	55%
	106	15	20-30	6.56	90%
	109	15	10-20	9.78	95%
	113	15	10-20	4.14	70%

* Based on estimated survival rates for steelhead embryos using data reported by Lotspeich and Everest (1981).

survival relationships developed by Lotspeich and Everest (1981) and presented earlier in this report. Many of the same caveats applied to chinook survival-to-emergence indices should be applied to these for steelhead. The most notable exception is that survival-to- emergence rates for steelhead were obtained using data on actual steelhead embryos (Lotspeich and Everest 1981).

The two lowest survival indices are for stations immediately downstream of Trout Creek (Station 615) and Buck Hollow Creek (Station 95), both of which contribute high sediment loads to the Deschutes during high flow periods. Survival indices are higher than expected for samples from nearly all of the steelhead stations in Section IV (55-95%).

SPAWNER USE OF HABITAT

Chinook

As part of their baseline study, OSGC biologists conducted a number of counts of fall chinook redds along most of the 100.1 miles of the lower Deschutes. These counts were conducted using drift boats and a fixed-wing aircraft. OSGC biologists separately recorded the number of chinook redds visible on each spawning bar in the river.

Since completion of the OSGC study, counts of chinook redds in the river have been less detailed. In most years since 1972, the ODFW has conducted aerial counts of chinook redds in selected index reaches of the river from a helicopter. The number of redds within each index reach has been recorded but no distinction has been made as to the location of redds within the reaches (Table 17; Figure 26).

Table 17. Annual redd counts (redds/mile) made during fall aerial surveys of chinook spawning areas in specific reaches of the lower Deschutes River, Oregon. Low water clarity depressed counts for all reaches in 1981 and for those reaches counted in Section IV during 1983.

			YEAR											
R.M.[1]	Name	Section	65	66	72	74	75	76	77	78	79	80	81	83
99.5	Jackson	I	6	9	68	1 8	215	255	165	75	3	4°	38	6[a]
98.5	Disney	I	40	21	58	101	8°	112	90	105	130	125	112	47
94.5	Dry Creek	II	13	3	29	56	65	82	65	33	15	'00	31	13
85.5	Annie Dick	II	45	32	36	56	75	87	27	42	27	.25	30	7
80.5	Above Kaskela	III	4'	'8	12	2'	8	43	13	°3	3	132	1	[a]
70.5	Red Birch	III	2.	.6	65	5o	49	80	51	.2	5	121	0	.
58.5	Above Nena Creek	III	9	14	37	6	6	42	4°	5	8	22	0	6
52.5	Above Maupin	III	2°	33	6°	3	4	50	8°	4	9	15	2	1
33.3	Gert Ca°y°°	V	°	47	62	[a]2	25	85	5°	8	53	71	45	[a]
31.5	Cedar Island	'V	9	24	46	47	6	50	°5	0	30	26	37	12
28.5	Rattlesnake Island	'V	2	10	2	4	2	28	°0	0	0	0	8	0
17.5	Bull Run	'V	18	15	25	2	6	48	.4	8	51	28	18	8
10.5	Fall Canyon	'V	23	39	8	:0	6	6	2	2	6	8	1	6

1 midpoint of reach; all reaches were 1 mile long except for Gert Canyon (1.5 mi.).

CHINOOK REDD COUNTS

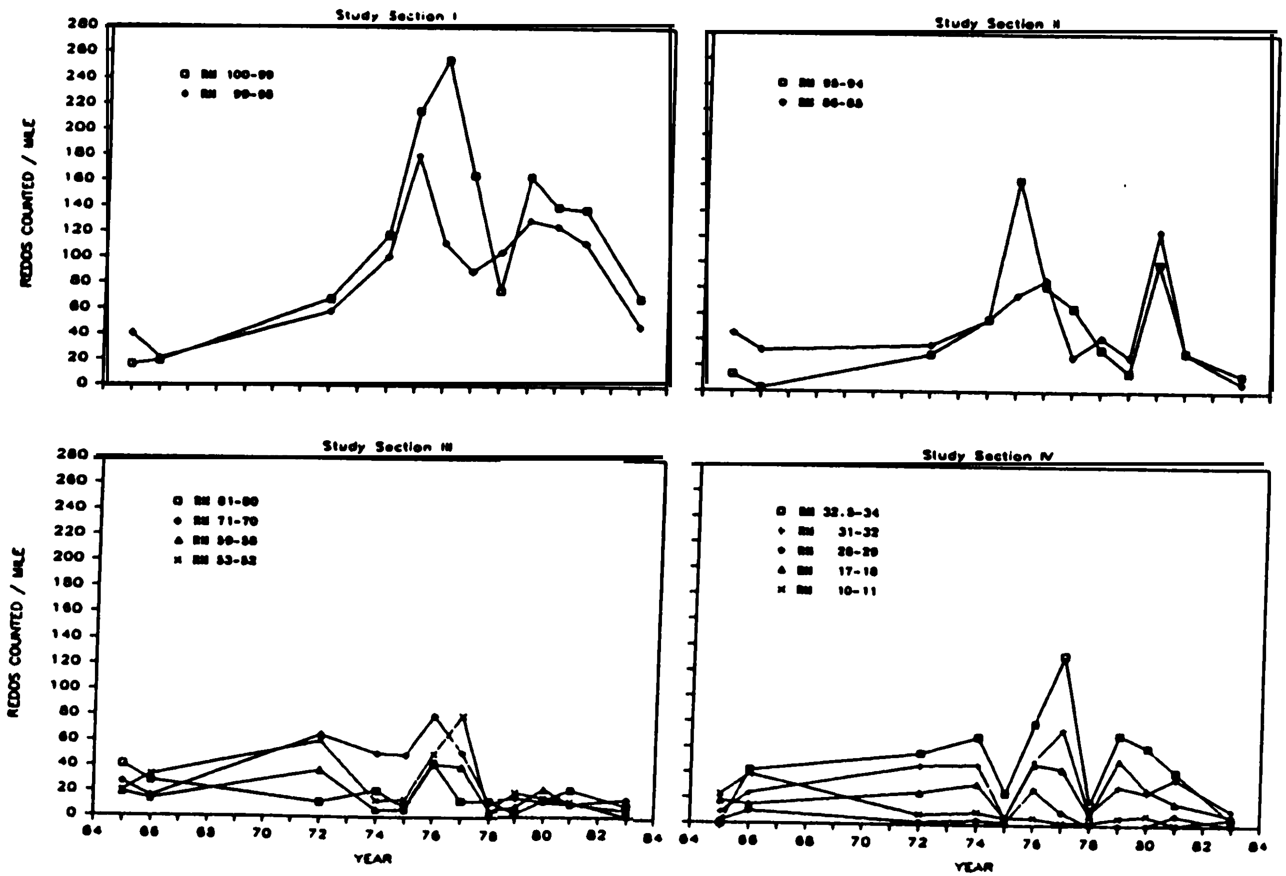


Figure 26. Annual fall chinook redd counts by year for specific index reaches of the lower Deschutes River, Oregon. Redd counts presented were made by the Oregon Stat Game Commission (1965-66) and by the Oregon Department of Fish and Wildlife (1972-83).

Attempts to make detailed counts of fall chinook redds in the Deschutes during 1984 were unsuccessful because of bad weather and poor water conditions. Without this information there are no current data available which can be used to compare present versus past spawner use of specific gravel bars in the Deschutes. This is unfortunate because there are a number of historical chinook spawning areas in the river where it is suspected that substantial shifts in spawner use patterns have occurred. Observations made during this study suggest that chinook spawners may have completely abandoned a number of spawning dunes in Section I and may no longer utilize relatively shallow spawning areas elsewhere in the river to the extent they did historically. According to limited observations in 1984 and conversations with OSGC study team members, Deschutes chinook may be spawning in deep water to a greater extent now than during the time of the baseline study.

Observations of chinook spawners made during this study indicate that areas most intensely used by fall chinook in the river tend to be those with the best sorted and apparently highest quality gravels. Of the gravel bars sampled during this study, the greatest numbers of chinook spawners and redds were seen at or near those bars having the highest permeabilities or Fredle index values. In contrast, the fewest spawners and redds were observed in Study Section III, where chinook spawning areas which were sampled had gravel with the lowest Fredle indices. Although this greater use of high quality gravels was not unexpected, the degree to which fall chinook modify the physical characteristics of some spawning areas in the Deschutes raises the possibility that they play a role in creating good spawning habitat in the river.

The OSGC noted that most chinook salmon spawning did not occur beyond "measurable limits" (Aney et al. 1967). The implication of this was that most fall chinook spawned in areas that could be waded by OSGC biologists. During our study, however, few areas where salmon spawned appeared limited by depth alone. Most fall chinook spawning took place in areas of deep water having relatively high current velocities. On one occasion, aerial observations revealed heavy fall chinook use of two large deposits of gravel in deep water within Section IV which were not previously known to be used by spawners. This and other heavy use of gravel deposits in deep areas of the lower river may reflect changes in spawner use patterns since the OSGC study (or the 1964 flood).

Steelhead

High water conditions in the Deschutes and turbid flows below Trout Creek delayed trout redd counts in 1984 until after most steelhead spawning and a large portion of resident rainbow trout spawning in the river had been completed. While it is generally possible to identify redds by their distinctive contour for a considerable period of time in the Deschutes, it was frequently difficult to determine whether a steelhead or large resident rainbow trout had constructed a particular redd. This problem of redd identification, which was also experienced by the OSGC in the 1960's, was difficult to resolve because both steelhead and resident trout tend to spawn in the same areas of the river. Nearly all steelhead and resident rainbow trout redds counted were found in areas where surface gravels were predominantly between l/4 and 3 inches in diameter (gravel classes I and II). Gravel of this size was found almost exclusively around islands, in side channels, and along the river margins.

All resident rainbow, steelhead and "unclassified" trout redds which were counted in 1984 were pooled into a single "trout redd" grouping for comparison to the results of redd counts made by the OSGC. A complete summary of redd counts made during this study and a breakdown of the trout redds counted in each ten mile reach of the lower Deschutes are given in Appendix XVI.

The number of steelhead, resident rainbow and unclassified trout redds counted in each study section during 1984 are presented in Table 18. Over half of the total 1,283 trout redds counted along the entire 100.1 miles of the lower Deschutes were found in Section II. Less than two percent of all redds counted in the river were seen below White River in Section IV.

Figure 27 presents the number of trout redds counted per river mile in each of the four study sections in 1984. Trout spawning activity in 1984 was most intense in Section I, less intense in sections II and III, and least intense in Section IV. This same pattern was observed by the OSGC in the mid-1960's, and reflects the importance of trout

Table 18. Steelhead, resident rainbow, and unclassified trout redds counted in each of four study sections of the lower Deschutes River, Oregon in 1984.

Study Section	Steelhead	Resident Rainbow	Unclassified	Total Trout Redds
I	0*	0"	222	222
II	63	87	507	657
III	69	32	300	401
IV	14	9	0	23
Totals	146	128	1029	1283

* no positive identification because of lack of concensus among field personnel.

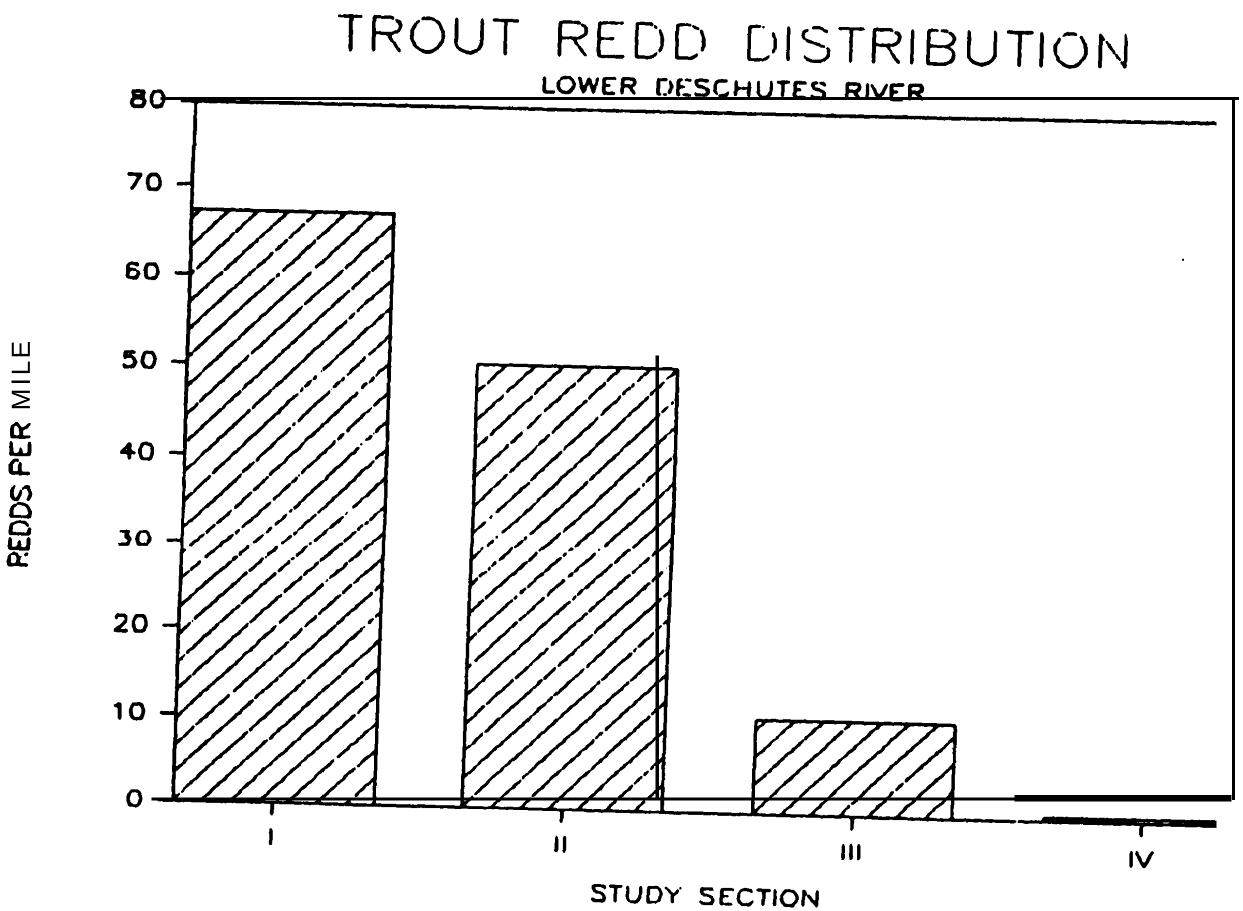


Figure 27. Trout redds counted per mile of river in each of four study sections of the lower Deschutes River, Oregon in 1984.

spawning habitat at the upper end of the study area. It is difficult to say whether this distribution of spawning activity reflects higher gravel quality in the upper study sections, greater resident trout population in those sections, or the fact that there is generally more spawning gravel available for trout per mile of river at the upper end of the study area. However, the quantity of trout spawning gravel per mile in each study section declines in the downstream direction just as redd densities (i.e. redds/mile) do.

Most of the trout spawning gravel found in sections I, II and III is heavily utilized by spawners. This does not seem to be the case in Section IV, where deposits of gravel suitable for use by spawning trout are most limited. Distinct redds were <u>not</u> found at a few gravel bars in Section IV which have gravel quality (i.e. calculated Fredle indices) similar to that of a number of well-used spawning areas sampled in the upper study sections. The absence of visible redds at these Section IV gravel bars may have been due to: 1) a flattening of redd contours by relatively "flashy" flows before the bars were checked for redds; 2) the presence of gravel too easily mobilized in those areas of Section IV with reasonable gravel by high flows (due to a high sound content) to be attractive to spawners; 3) low resident trout populations in the reach: or 4) possible spawning migrations of resident trout from Section IV to areas upstream.

Spawning site selection by steelhead and resident rainbow trout in the river does not appear strongly affected by the gravel quality differences observed at sampling stations. The second most heavily used spawning area in the river (according to redd counts) was the sampling station below Trout Creek, which had the second worst gravel quality (in terms of Fredle indices) of the 13 steelhead spawning areas sampled.

Figure 28 contrasts the distribution of trout redds between the four study sections in 1984 with that of trout redds counted in the river in 1963, 1964, 1965 and 1966. The 1984 figures are based on a single peak redd count made at each gravel bar in the Deschutes River after most trout spawning was completed . The OSGC figures are the result of repeated counts of gravel bars which may have accounted for some superimposed redds. Thus the current figures may

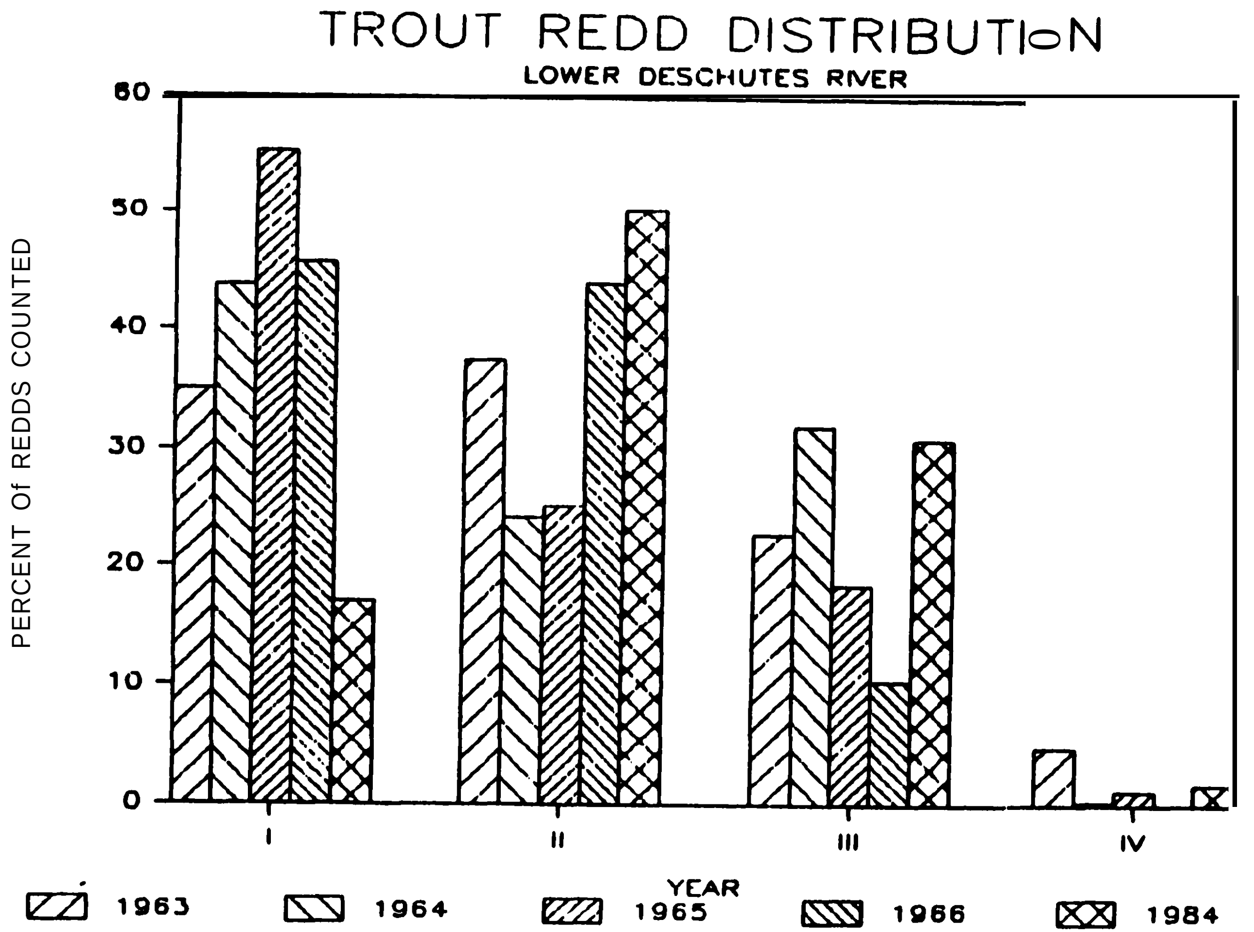


Figure 28. Percentage distribution of trout redds counted in each of four study sections of the lower Deschutes River, Oregon by the Oregon State Game Commission (1963, 1964, 1965, 1966) and during this study (1984).

be comparatively conservative for areas where spawning activity is most intense and redd superimposition most likely. However, it is doubful that this would have a major effect upon the redd distribution depicted for 1984 in the figure.

Figure 28 suggests that although trout spawning activity is presently most intense in Section I (see Figure 27), a considerably smaller percentage of all trout spawning in the lower Deschutes is taking place in Study Section I than was occurring there in the mid 1960%. The OSGC counted more trout redds in Study Section I than in any of the other three sections both before (1963; 1964) and after (1965; 1966) the 1964 flood. More trout redds were found during this study in both sections II and III than in Study Section I. This apparent change in the distribution of trout spawning activity in the river is significant because it may reflect a response of spawners to reductions in the total area of trout spawning gravel in Section I since completion of the OSGC study.

The results of redd counts conducted during this study and those made by the OSGC after the 1964 flood were tabulated to see if trout in the Deschutes are spawning at more or fewer locations now than during the baseline study. It was reasoned that a reduction in the number of areas used could indicate a reduction in quality or quantity of spawning habitat in the river.

Table 19 contrasts the number of gravel bars known to have been used by spawning steelhead or resident rainbow trout during the first two spawning seasons after the 1964 flood with the number of gravel bars at which evidence of trout spawning activity was observed in 1984. During the two years after the 1964 flood, the OSGC documented steelhead or resident trout spawning on 59 gravel bars in the lower Deschutes. In 1984, we also found evidence of trout spawning at 59 gravel bars. Evidence of trout spawning was found at fewer gravel bars in both sections I and II during this study than in 1965 and 1966. However, trout spawning appears to have taken place at more gravel bars in sections III and IV during 1984 than in the two years following the 1964 flood (1965; 1966).

Mainstem spawning habitat for summer steelhead in the Deschutes Basin is not abundant (Table 20). This has

Table 19. Numbers of gravel bars in each Study Section at which evidence of steelhead or resident rainbow trout spawning was observed by the OSGC during the two years following the 1964 flood (1965-1966) and by Buell and Associates in 1984.

Study Section	1964-65	1984
I	10	7
II	23	18
III	23	29
IV	3	5
Total	59	59

Table 20. Numbers of summer steelhead (Salmo *gairdneri*) which could be accomodated by the spawn-ravel avel identified during this study in each Study Section of the lower Deschutes River, Oregon.

Study Section	Pairs of Spawning Summer Steelhead Accomodated[a]	Summer Steelhead Accomodated[b]
I	734	1,468
II	2,205	4,410
III	1,922	3,844
IV	452	904
ALL	5,313	10,626

a Based on a redd density of 4.82 yd2/redd (Hunter 1973) and the surface areas of Class I and Class II spawning gravels identified during this study.

b Assuming a sex ratio of 1:l.

apparently been the case for some time (see, for example, Aney et al. 1967). Spawning gravels cataloged during this study could accomodate about 5300 pairs of spawning steelhead.

If the ODFW is correct in believing that steelhead in the Deschutes River drainage spawn predominantly in the mainstem, spawning habitat in the river might affect the size of its summer steelhead population. However, lacking conclusive data on the proportionate spawner use of tributary streams, we must reserve judgement on the adequacy of the amount of spawning habitat for these fish in the mainstem Deschutes.

STREAMFLOWS

One of the primary premises upon which this study was based is that spawning gravel in the Deschutes has been degraded due to altered flow regimes downstream of the PGE hydrocomplex. This premise was based on the record of effects of dams on spawning gravel in rivers throughout the Pacific Northwest and Canada, and a belief that the river was not experiencing scouring flows as frequently as it did prior to completion of the hydrocomplex. However, during this study it was found that hydrocomplex influences on flows downstream were far more complex than anticipated.

Since most bedload movement in streams takes place during high flow events, it was important to look at the magnitude and timing of peak flows in the river. Peak flow timing in the lower mainstem Deschutes has shifted since project cunpletion, but the magnitudes of the peaks experienced are similar to those of peaks which occurred under the pre-project conditions. In addition, seasonal differences in flow timing between the pre- and post-project periods have been nearly equalled by similar shifts in tributary flow patterns.

Flow duration curves display the percent of time that a given flow is matched or exceeded. Such curves are constructed from the historical flow records or subsets of the historical flow records for a particular gaging station. Once constructed, these curves can be used for a number of purposes, including comparisons of discharge characteristics at different stations and analyses of changes over time in the river discharge characteristics at a specific location.

Flow duration curves for the Deschutes River during the pre- and post-complex periods are given for both the Pelton and Moody gage sites in Figure 29. The curves indicate that high, mid-range and low flows at each location have generally been higher in the post-complex period than they were during the pre-complex period. For example, at Pelton (RM l00) streamflows exceeded one percent (9,040 v. 8,531) 50 percent (4,400 v. 4,210), and 99 percent of the time (3,200 v 3,110) have been greater since project cunpletion than during the pre-project period.

Flow duration curves for the pre and post-complex periods are presented for the White River gage in Figure 30. As is the case for the mainstem Deschutes, high flows in the White River have generally been greater since completion of the hydrocomplex than during the pre-complex period. However, unlike the mainstem lower Deschutes, mid-range and low flows in the White River have been slightly lower since hydrocomplex completion than they were during the pre-complex period.

Differences in the shapes of the pre- and post-complex flow duration curves for White River suggest that runoff

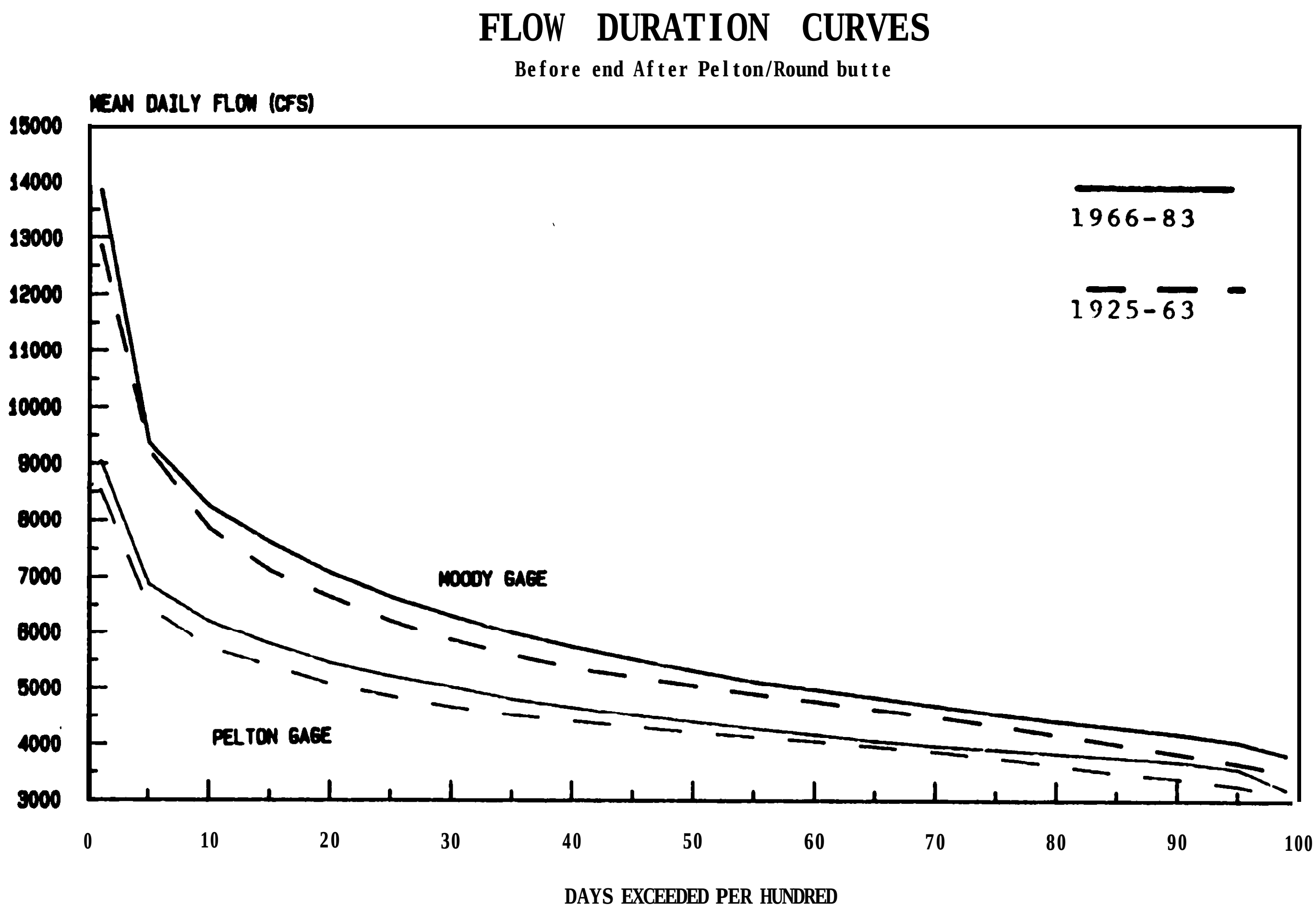


Figure 29. Flow duration curves for USGS stream gages at Pelton (RM 100.) and at Moody (RM 1.3), both before (1925-63) and after (1966-83) full operation of the Pelton/ Round Butte hydroelectric complex.

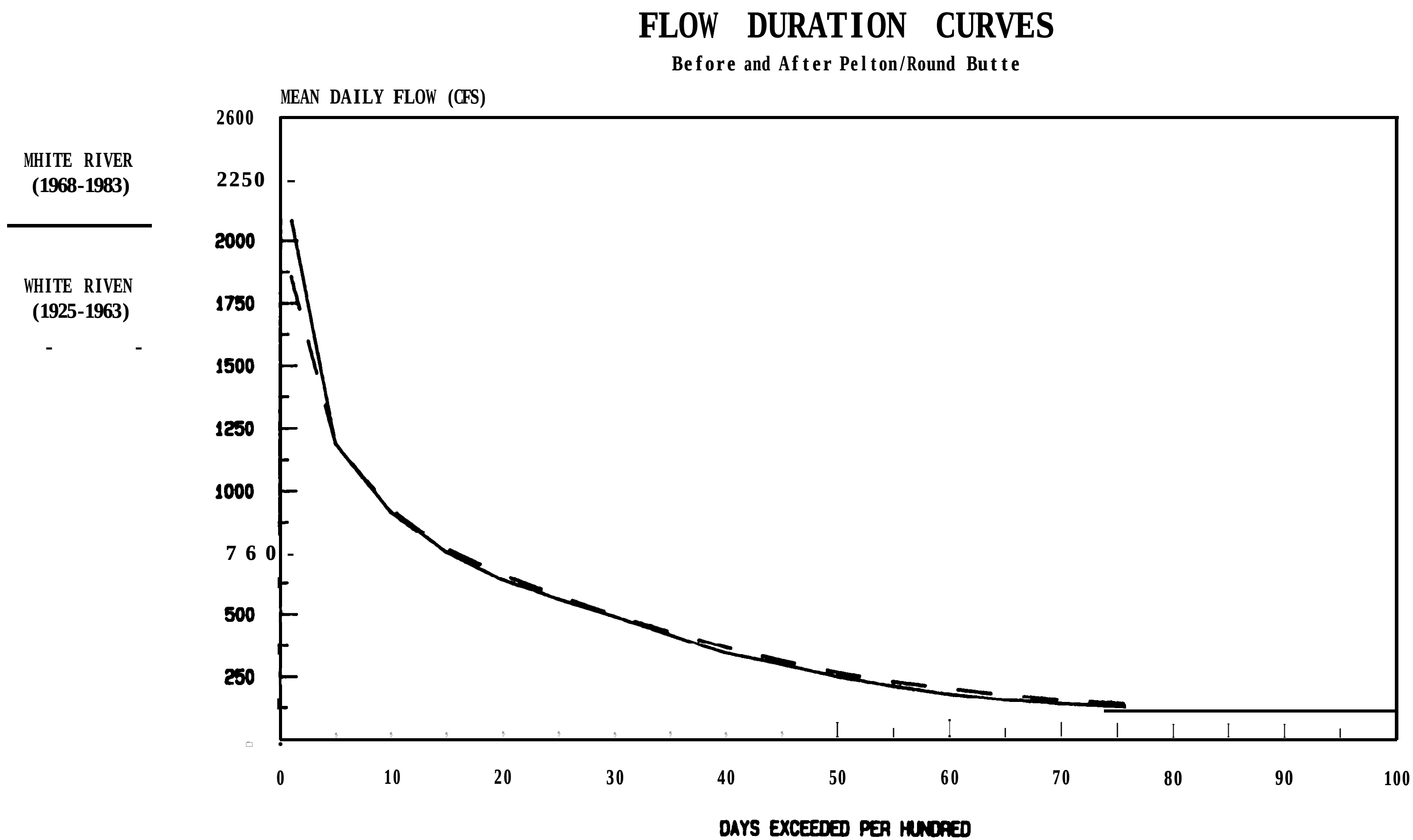


Figure 30. Flow duration curves for the USGS stream gage on White River near Tygh Valley both before (1925-63) and after (1966-83) completion of the Pelton Round Butte hydroelectric complex.

patterns there have been slightly "flashier" since complex completion than they were during the pre-complex period. Such a change could result from different patterns of precipitation during the two periods or from changes in the ability of the watershed to store water during storm events. However, examinations of a number of flood hydrographs for the White River gage during both the pre- and post-project periods did not provide conclusive evidence of such a hydrologic change.

Seasonal streamflow patterns for the mainstem Deschutes below Pelton Reregulating Dam have been substantially different from those recorded prior to completion. Figure 31 contrasts the mean monthly flows recorded during the periods before and after completion of the hydrocomplex at both the Pelton and Moody gage sites. Streamflow at both locations has been greater during all months but April at Pelton and all but April and May at Moody since the complex was completed. These differences are significant because spring runoff typically accounted for the greatest sustained flows in the Deschutes during the period prior to completion of the hydrocomplex, In contrast, mean flows have generally been highest during the winter months since Round Butte Dam became optional.

MEAN MONTHLY FLOWS AT PELTON AND MOODY

Before and After Pelton/Round Butte

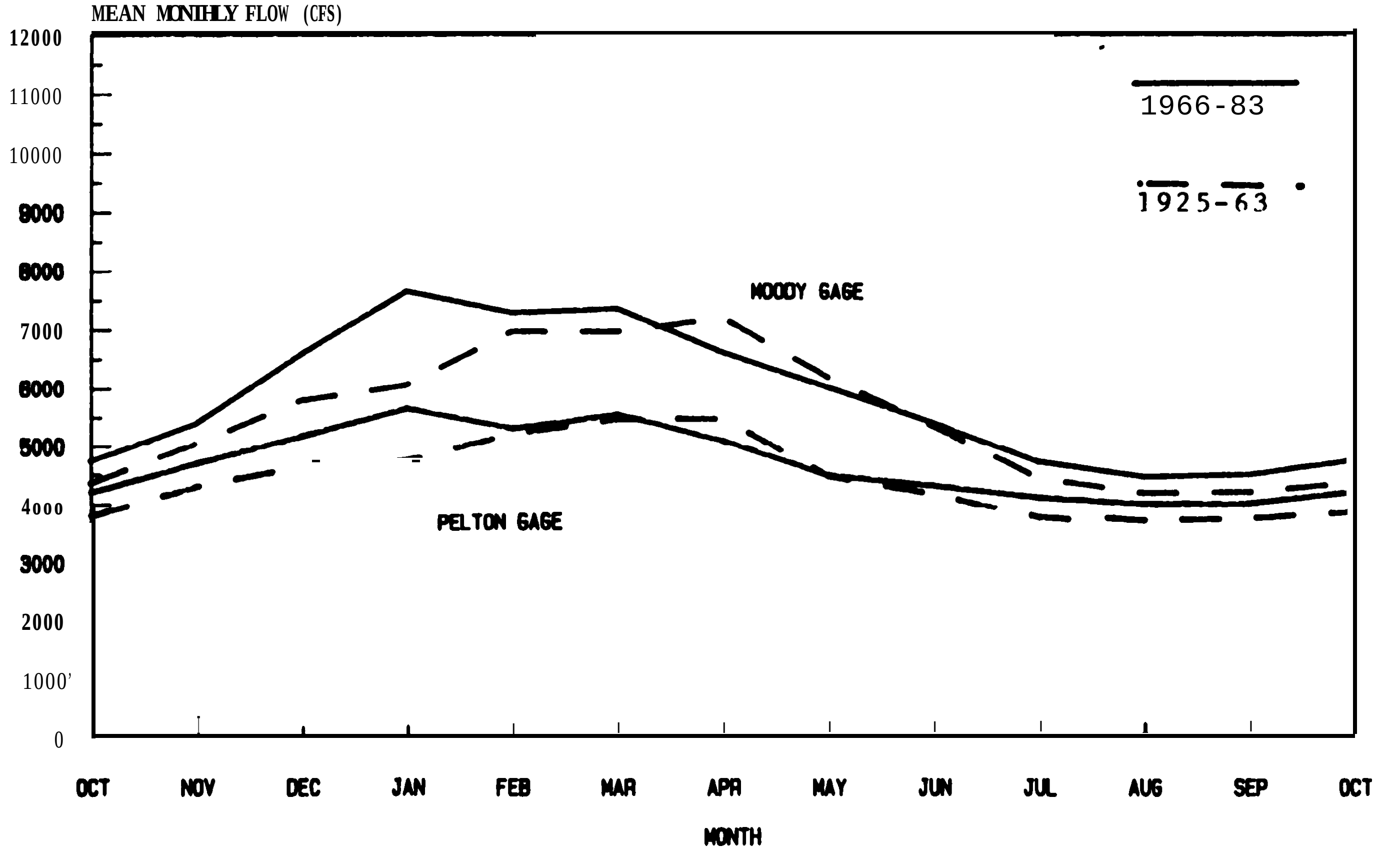


Figure 31. Mean monthly flows for the mainstem Deschutes River at Pelton (RM 100) and at Moody (RM 1.3) both before ((1925-63) and after (1966-83) full operation of the Pelton/ Round Butte hydro-electric project.

Figure 32 presents mean monthly flows in White River near its confluence with the Deschutes during the pre- and post-complex periods. Like the mainstem Deschutes, White River has experienced an apparent seasonal shift in discharge patterns. Mean monthly flows for White River have also been lower in the spring and greater in the winter since project completion. Unlike the mainstem Deschutes, however, White River has had lower mean flows during the summer and fall months since completion of the PGE complex.

Historical flow records for tributaries to the lower Deschutes, other than White River, are limited and thus not amenable to pre- and post-project analyses. However, the difference between Deschutes River discharge at Moody and that at Pelton is attributable to the combined flow of all the lower river's tributaries. With this in mind, a canposite of the mean discharge of all tributaries was determined for each month of the year. The total mean monthly flow of tributary streams was calculated as the difference between the mean discharge at Moody and the mean discharge at Pelton for each month of the year. Figure 33 contrasts the total mean monthly flow of all lower

MEAN MONTHLY FLOWS FOR WHITE RIVER

Before and After Pelton/Round Butts

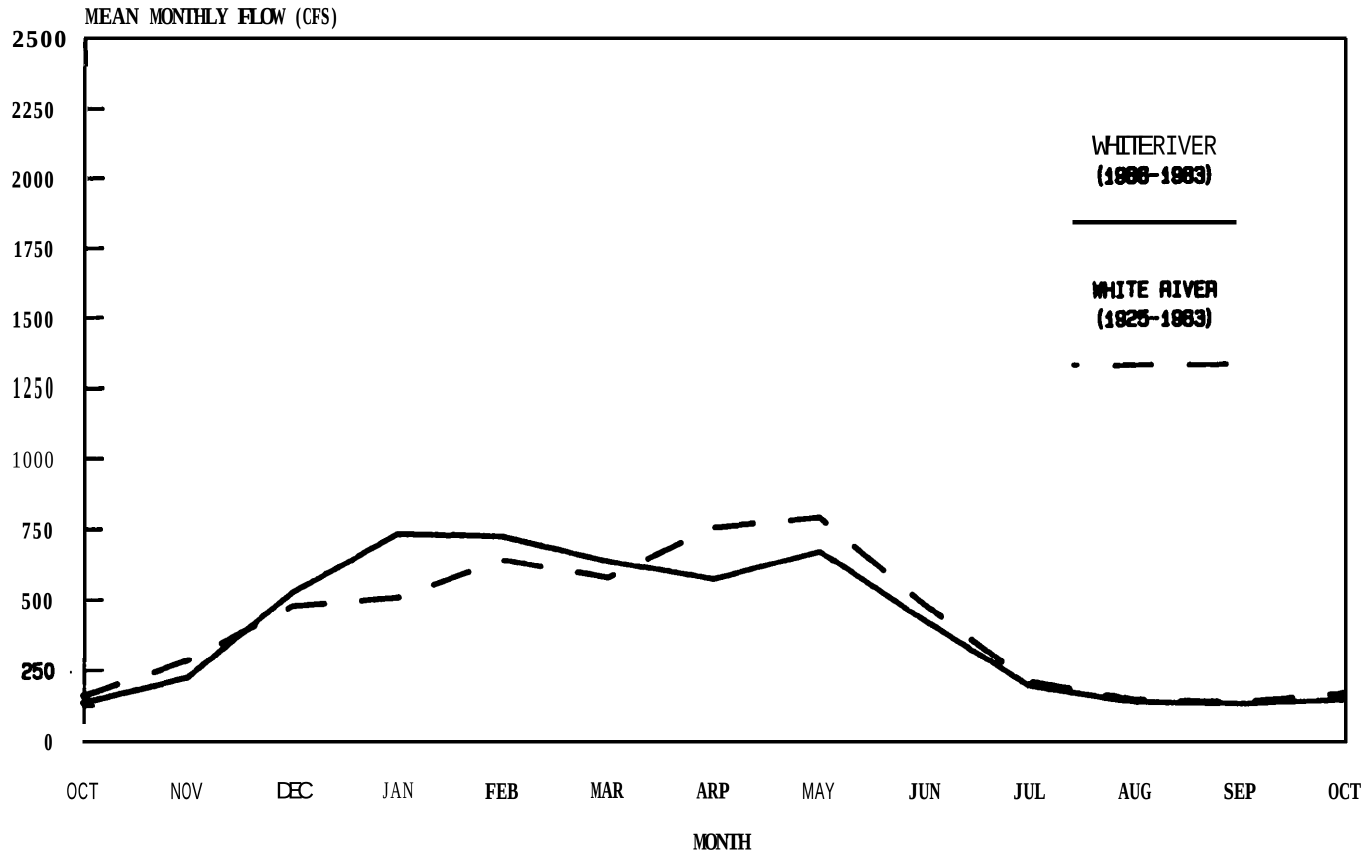


Figure 32. Mean monthly flows for White River near Tygh Valley both before (1925-63) and after (1966-83) completion of the Pelton/ Round Butte hydrocomplex.

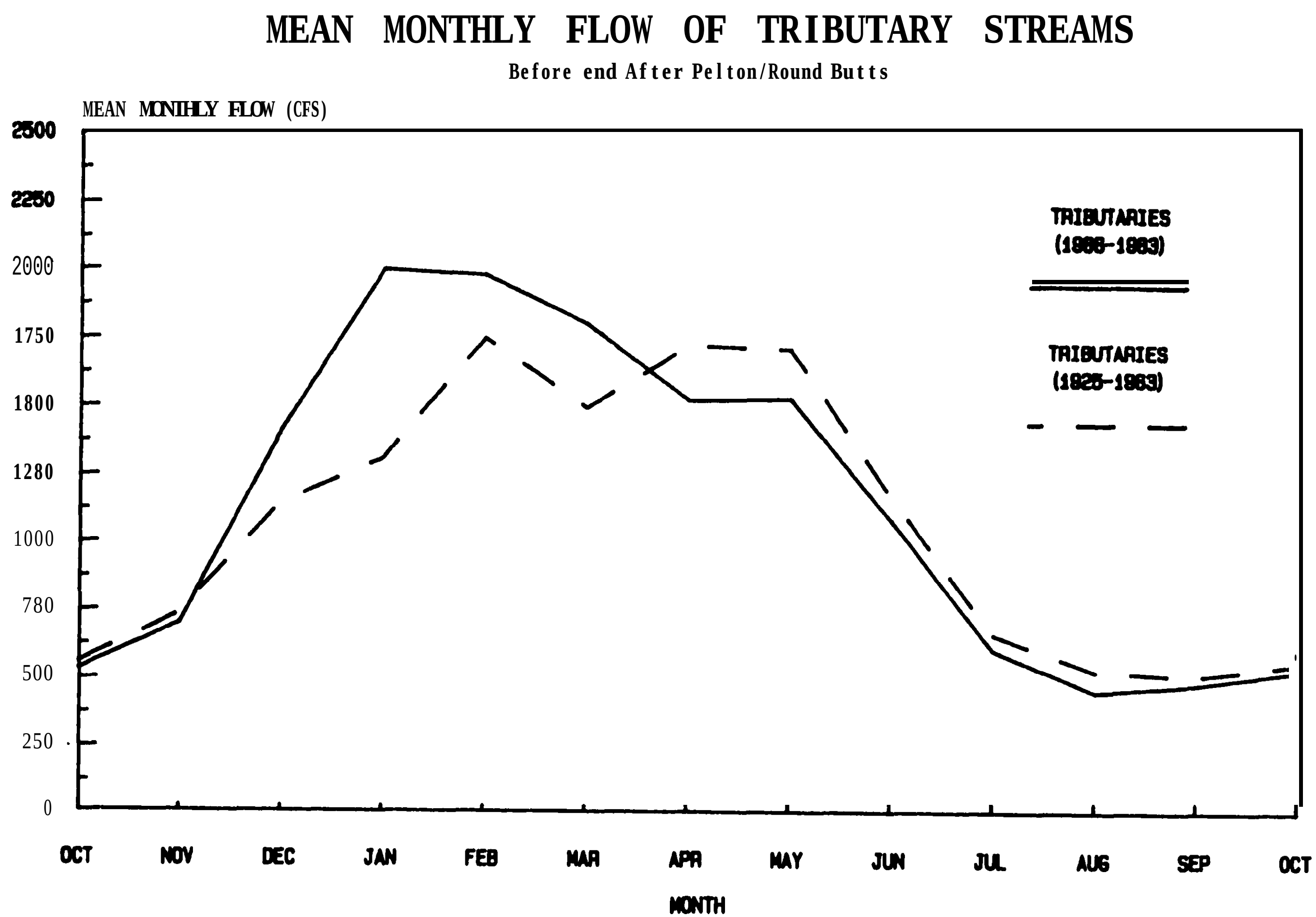


Figure 33. Combined mean monthly flow of immediate tributaries to the lower Deschutes River, Oregon before (1925-63) and after (1966-83) full operation of the Pelton/ Round Butte hydroproject.

Deschutes tributaries during the pre and post hydrocomplex periods. The differences noted are similar to those recorded for White River. Mean flows for winter months are greater for the post-complex period while those for the spring, summer and fall months are lower.

Mean monthly flows in both the mainstem Deschutes and its tributaries have generally been higher in the winter and lower in the spring during the post-complex period than they were during the pre-complex period. Overall, these differences reflect an apparent shift in runoff timing in the lower Deschutes drainage from spring toward winter. The fact that both the Deschutes and its tributaries are responding in a similar manner suggests that the seasonal changes in mainstem flow patterns are at least partially due to factors other than the presence of the PGE hydrocomplex. Factors other than the hydrocomplex which might be involved in this apparent shift include changes in precipitation patterns, water storage elsewhere in the Deschutes Basin, or possible reductions. in natural storage of water resulting from land use practices.

Figure 34 gives the maximum daily, minimum daily and average annual flow in the Deschutes River at Pelton Gage (RM 100.1) for water years 1925 through 1983. Maximum daily flows recorded at Pelton gage during this period have varied from 5160 cfs in 1964, to 15100 cfs in 1965. Despite concern that the PGE hydrocomplex has reduced peak flows in the lower Deschutes, maximum daily flows for water years following completion of the PGE hydrocomplex have not been substantially lower than those recorded prior to complex completion. In fact, the average of these peak flows for the post-complex period (WY 1966-83) is 8700 cfs, over five percent greater than the average of 8820 cfs for the pre-complex period (WY 1925-1963).

The river discharge necessary to mobilize bedload in the Deschutes near the Pelton gage (i.e. Study Section I) is not known and cannot be determined from available information. It is therefore not possible to determine whether the discharge necessary for cleansing gravel of accumulated fine sediment has been experienced more or less frequently since completion of the hydrocomplex. However, upon completion of their study of spawning habitat in the

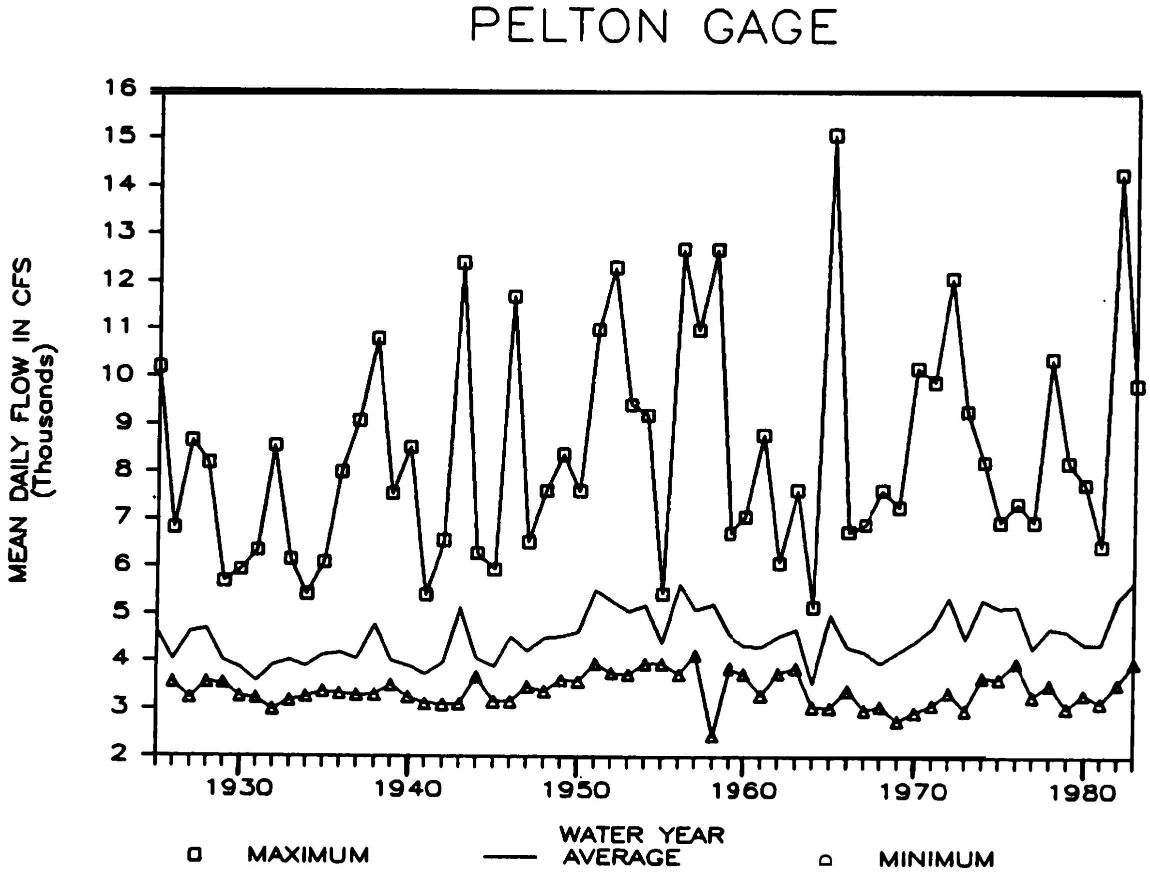


Figure 34. Maximum, mean, and minimum daily flows in the lower Deschutes River, Oregon at Pelton (RM 100) for each water year from 1925 through 1983.

Deschutes, the OSGC recommended annual "flushing" flows of at least 8500 cfs of 36 hour duration at Pelton gage to maintain gravel quality downstream.

If the recommended "flushing flow" is adequate to cleanse gravel in the Deschutes below Pelton Reregulation Dam, then gravel in the river has been cleaned about as frequently since complex completion as it was before completion. Maximum daily streamflow at Pelton gage exceeded the 8500 cfs suggested by the OSGC during 16 of 39 years (41%) in the pre-complex period and has done so in 7 of 18 years (39%) during the post-complex period. If the recommended 8,500 cfs is insufficient to mobilize gravel and remove fine sediment, the frequency of occurrence of actual cleansing flows may have increased since the hydrocomplex was completed. Without knowing the threshold flow for actual gravel cleaning, no firm conclusion can be made on this point.

Annual minimum flows recorded at the Pelton gage site have generally been lower since completion of the PGE hydrocomplex than they were during the period of record before the complex was completed. Average annual minimum flow (minimum daily flow) for the post-complex period has been 3290 cfs, while that for the pre-complex period was 3460 cfs. Average annual flows at Pelton during the post-complex period (mean=4660: n=18) have been greater than those of the pre-complex period (mean=4445; n=39).

Recent changes in the seasonality of peak flows in the lower Deschutes are depicted in Figure 35. The exceedance curves given show differences in the river discharge exceeded five percent of the time for each month of the year during the pre and post- complex periods. The curves suggest that there has been a shift in peak flow timing from spring toward winter at both gages.

Figure 36 shows that seasonal timing of peak flows in unregulated White River appears to have shifted in the same direction as that for the mainstem Deschutes. This finding is important because it indicates that the change in peak flow timing in the mainstem is at least partially due to factors other than the PGE hydrocomplex. The observed trend toward earlier peak flows in the winter caused by any of the factors noted earlier as plausible explanations for recent shifts in mean monthly flows.

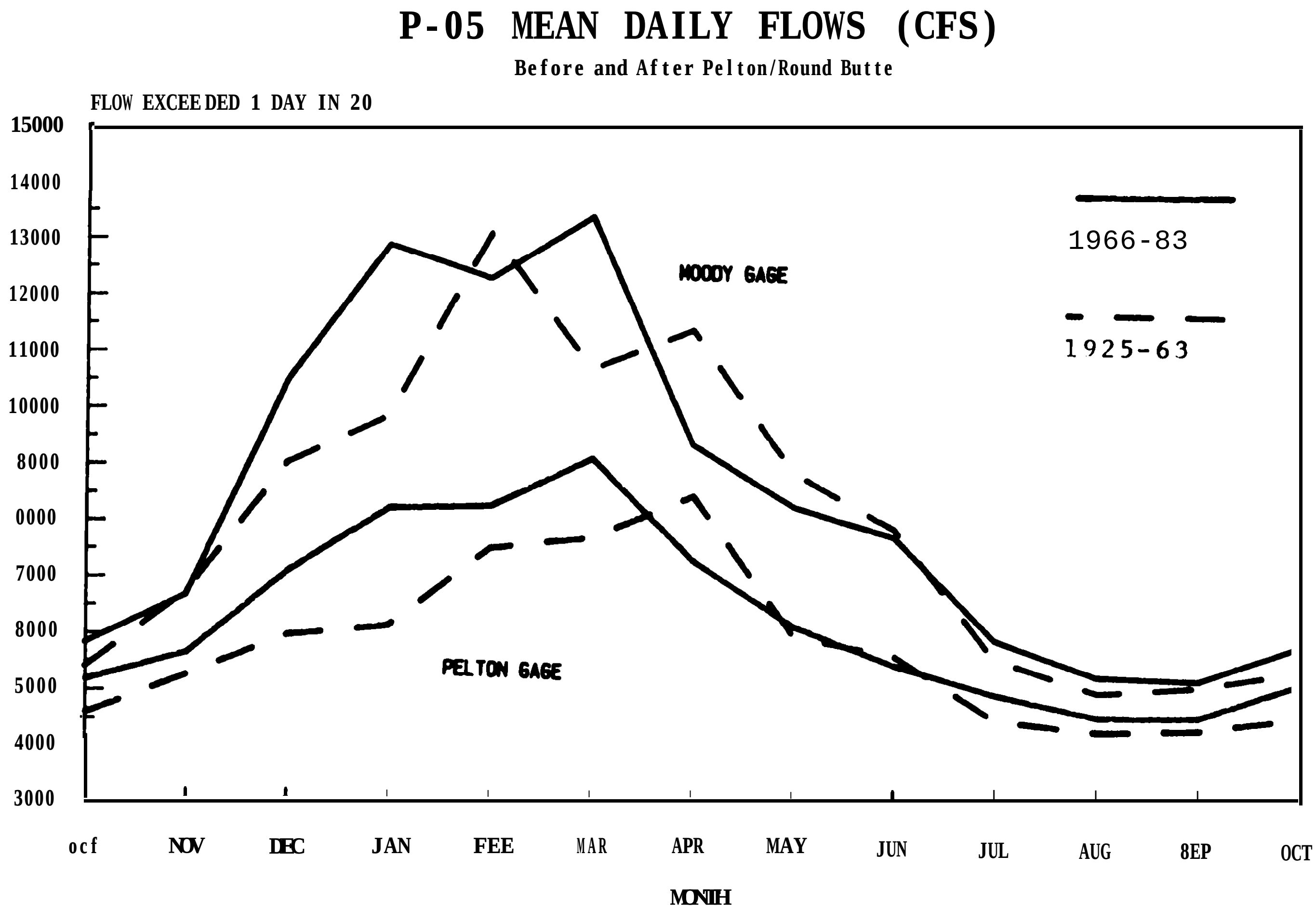


Figure 35. Five percent exceedance flows, by month, for the Deschutes River at Pelton (RM 100) and at Moody (RM 1.3) both before (1925-63) and after (1966-83) completion of the Pelton/ Round Butte hydrocomplex.

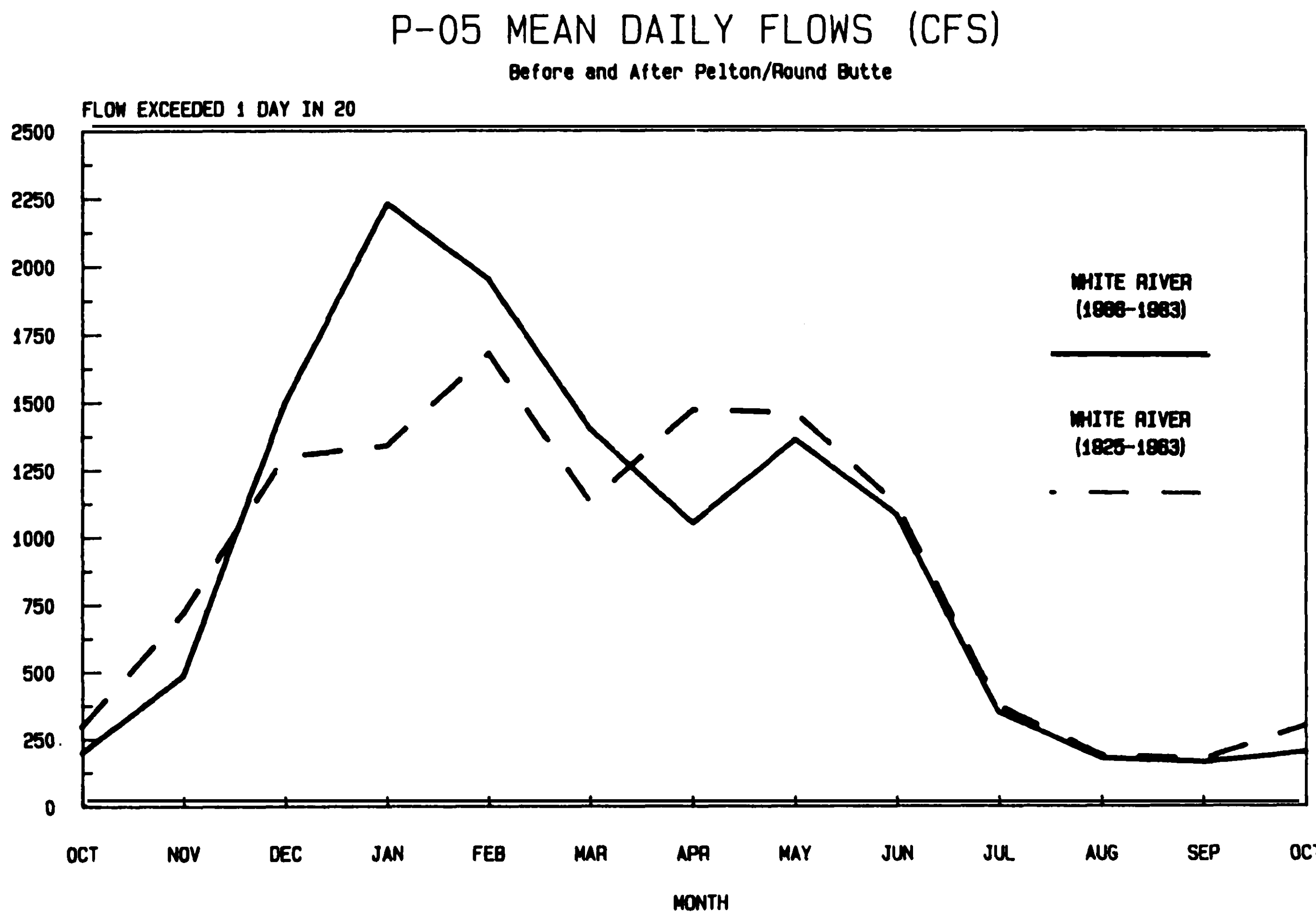


Figure 36. Five percent exceedance flows, by month, for White River near Tygh Valley both before (1925-63) and after (1966-83) full operation of the Pelton/ Round Butte hydroelectric complex.

Mean annual discharge for the Deschutes basin has generally been greater since the PGE hydrocomplex was completed than it was during the pre-complex period. For this reason it is conceivable that the effect the PGE hydrocomplex has on flows in the Deschutes downstream could be greater than suggested by our pre- and post-complex streamflow analyses. Dam-caused reductions in streamflow during periods of greater natural runoff than would be expected on the basis of historical flow records may be masked by a general abundance of water. For this reason, it is important to look specifically at available data on the ways in which the complex does change the flow regime in the lower Deschutes.

Information on active water storage capacity and the volume of seasonal runoff typically stored each year in major reservoirs within the Deschutes Basin provides a good perspective on the relative importance of the PGE hydrocomplex in altering streamflow in the lower Deschutes River (Table 21). Water storage in reservoirs upstream from Round Butte Reservoir appears likely to have a very profound effect on streamflows in the lower Deschutes

Table 21. Year of first filling, usable storage capacity, and volume of runoff stored during typical years for major storage reseroirs in the Deschutes Basin upstream of the Pelton Reregulation Dam (RM100).

Reservoir(s)	First Filled	Usable Storage Capacity (1000's acre-feet)	Seasonal Run-off Typically Stored (1000's acre-ft)	Refer-ence
Pelton/Rereg.	1957	6.5	0	PGE
Round Butte	1964	273.9	19.8	PGE
ochoco	1919	46.5	24.0	OID
Rrineville	1960	153.0	60.0	OID
Crane Prairie	1922	48.0	36.0	ORWm
Wickiup	1942	200.0	140.0	ORWm
Crescent Lake	1922	80.7	20.0	ORWm
PGE HYDROCOMPEX		280.4	19.8	
OTHER MAJOR RESERVIRS		528.2	280.0	

a Difference between maximum and minimum pool volumes during a typical water year based on information provided by the source indicated. Actual storage of runoff is somewhat higher, particularly for Round Butte Reservoir, due to short term fluctuations in pool elevations.

PGE- Portland General Electric Co.
OID - Ochoco Irrigation District
ORWM- Oregon Watermaster

River. This effect may be greater than that of the PGE complex. The Pelton/ Round Butte hydroelectric complex accounts for 280.4 thousand (35 percent) of the 808.6 thousand acre-feet of active storage capacity present in the drainage above Pelton Reregulation Dam (RM 100). As well, the PGE complex stores about 19.8 thousand acre-feet of seasonal runoff during a typical year, only about seven percent as much runoff as is stored in major reservoirs upstream (280 thousand acre-feet).

The inflow/outflow records for the hydrocomplex show how the PGE dams modify flows in the lower Deschutes. During most winters, project inflow precedes project outflow by one or two days. Figure 37 relates the inflow/outflow pattern for the hydrocomplex in water year 1983, a year during which inflow was closely followed by outflow. It can be seen that the magnitude of outflow closely approximates that of inflow for both high and low flows. Time lags between inflow and outflow are usually small.

In some years, the inflow/outflow pattern for the hydroccrmplex is quite different than that shown for water year 1983. There are times when inflow and outflow

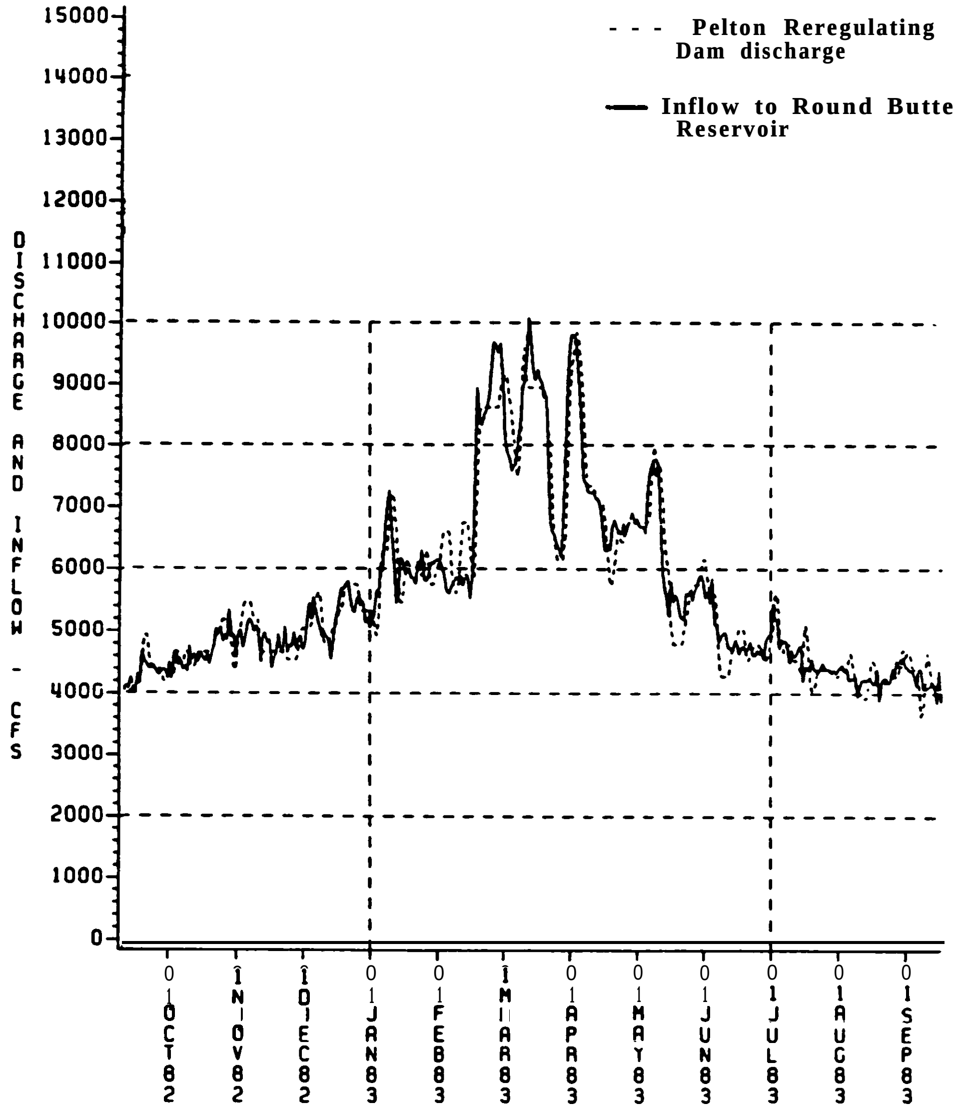


Figure 37, Coincident inflow'and outflow for the Pelton/ Round Butte hydroproject for water year 1983.

asynchrony develops in the winter. When this occurs, discharge below the project is relatively low when inflow is high, and relatively high when inflow is low. This type of asynchronous winter flow pattern has occurred to varying degrees since the hydroproject was completed. This pattern develops during years of inconsistent winter runoff and high demand for hydroelectric power generated by PGE.

A graphical representation of the relationship between project inflow and outflow during 1979, a water year of pronounced inflow/outflow asynchrony, is depicted graphically in Figure 38. It is readily apparent that the inflow/outflow relationship for that water year was quite different than that of 1983. When it occurs, this asynchronous discharge pattern can be particularly pronounced during periods of high flow from December through the end of April.

The degree of synchrony between peak winter flows in the lower mainstem Deschutes and those of its tributaries is important because these flows are probably responsible for much of the gravel movement in the drainage, both in tributaries and in the mainstem. Changing the relationship

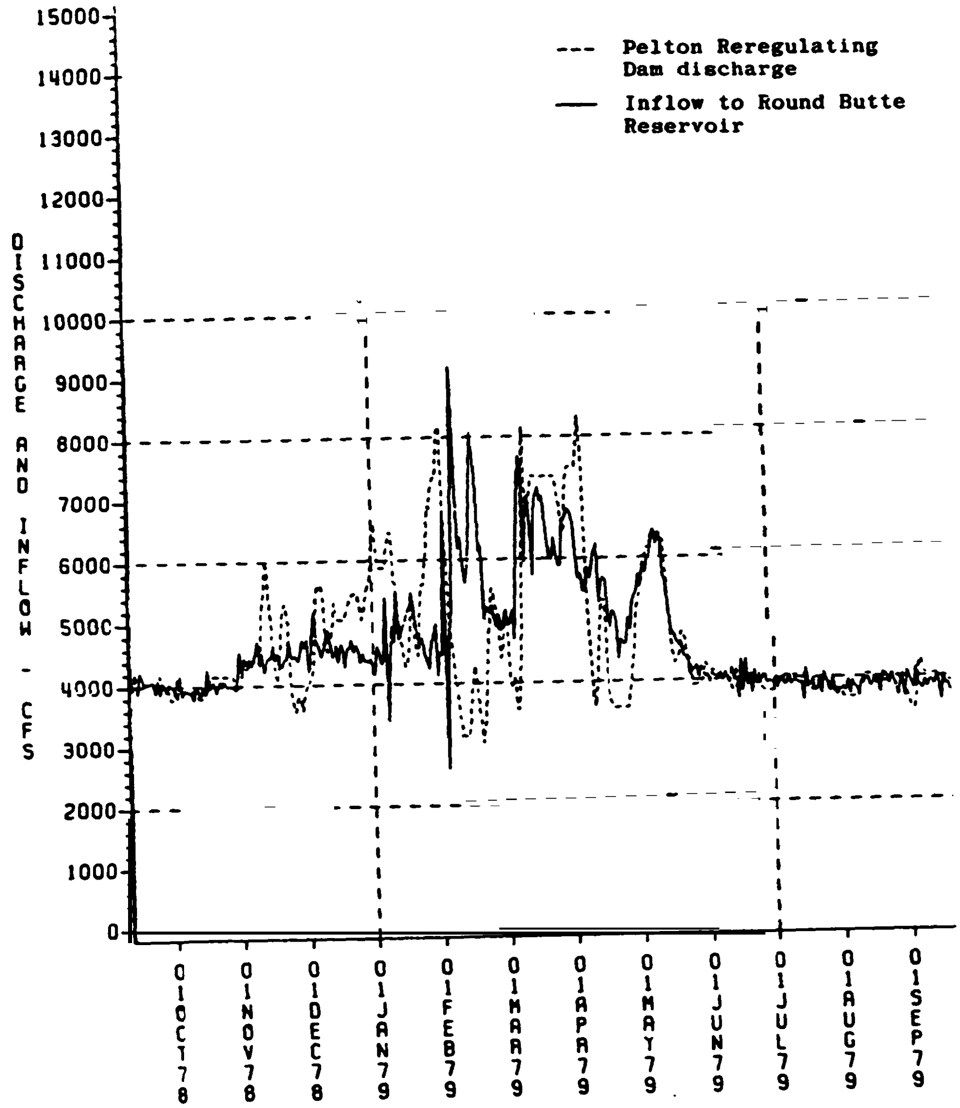


Figure 38. Coincident inflow and outflow for the Pelton/ Round Butte hydroproject during water year 1979.

between the delivery of bedload to the mainstem and the mainstem's ability to move that bedload when delivered could lead to a substantial change in depositional patterns in the mainstem Deschutes.

Such a change was experienced on the Deschutes late in 1964, when the largest flood recorded for the river was experienced. As has been the case in most of the largest floods on the Deschutes, the 1964 flood was triggered by warm rains which fell on an unusually large snow pack.

In December 1964, Round Butte Reservoir was filled for the first time, capturing the flood "spike" and dramatically altering flows in the river downstream. The magnitude of the effect that filling of the reservoir had on flows immediately below the PGE complex was extreme and will probably never be matched. Figure 39 shows the inflow/outflow pattern for the complex during the 1964 flood. Without the hydrocomplex dams, the maximum mean daily flow in Study Section I during the flood would have been approximately 18,900 cfs on 24 December. As it was, the maximum mean daily flow in Study Section I was only 15.100 cfs and occurred (four days after it would have) on

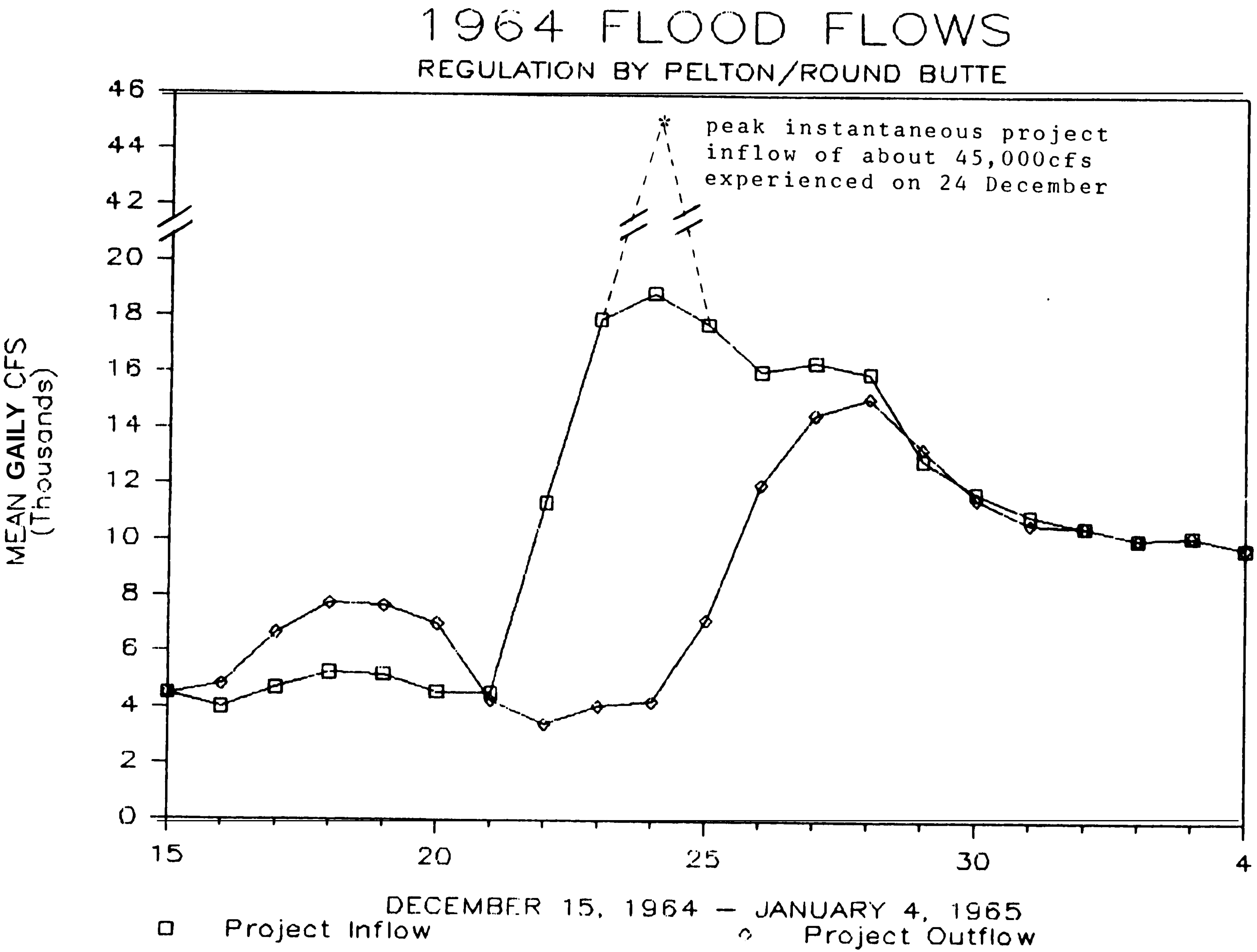


Figure 39. Storage of water by the Pelton/ Round Butte hydro-project (Round Butte Reservoir) during the 1964 flood.

28 December. In addition, the instantaneous peak flood discharge at Pelton would have reached approximately 45,000 cfs, (Don Ratliff, PGE, Madras, Oregon, pers. comm.) on 24 December, nearly three times the 15,800 cfs peak instantaneous discharge actually recorded four days later on 28 December.

Figure 40 presents mean daily discharges recorded by the USGS for the 1964 flood at Pelton, Moody and White River gages. While the highest mean daily discharges for the Moody and White River gage sites were recorded on 22 December, that for the Pelton gage came on 28 December. A large part of the six day difference in peak flow timing between the gages was due to the water storage in Round Butte Reservoir' depicted in Figure 39. By combining information given in Figure 39 with mean daily flows shown for the Moody gage in Figure 40, it is possible to estimate what flows at the Moody gage site would have been during the 1964 flood without the PGE complex in place. Without the hydrocomplex, the flood "spike" at Moody would likely have been in the neighborhood of 90,000 cfs, an increase of nearly 20% over the actual instantaneous peak flow of 75,500 cfs. The flood spike at Moody would also have come

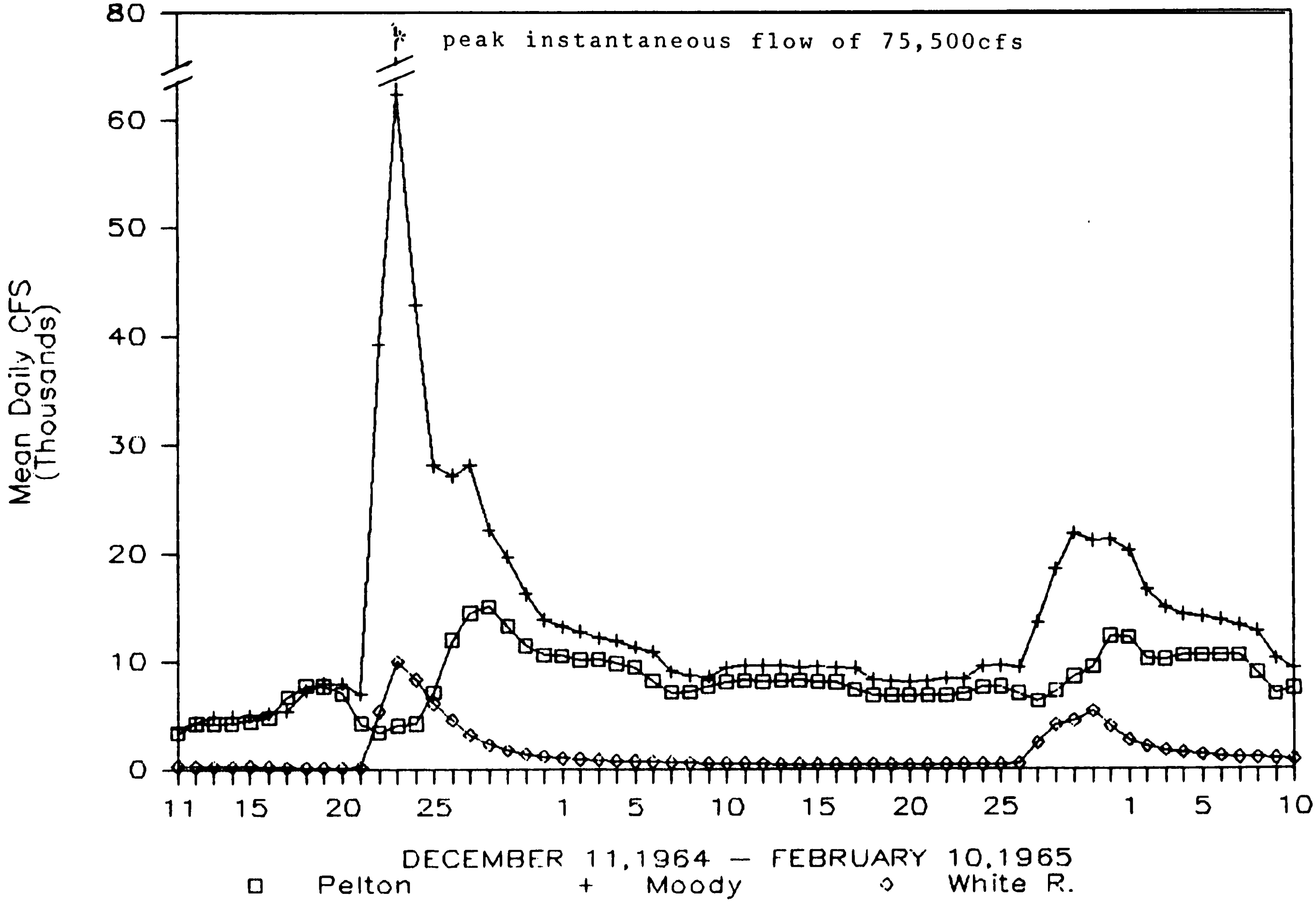


Figure 40. Discharge patterns for the Pelton, Moody, and White River gages during the 1964 flood.

two days later on 24 December, as opposed to 22 December. Additionally, without the PGE complex, extreme flows would have been experienced at Moody for a considerably longer time than they actually were.

Water storage in upper Deschutes Basin reservoirs above the PGE complex (e.g. Ochoco Reservoir, Prineville Reservoir) may also have played a significant role in modifying the magnitude and timing of the 1964 flood in the study area. This probably accounts for the fact that the flood crested later on the hydrocomplex inflow curve than it did at the Moody gage site (RM 1.3). Thus, the flood crest would have reached the Pelton Gage one or two days after the flood crest at the Moody Gage, even without the PGE dam in place. Even taking this lag into account, however, it is certain that the PGE complex played a major role in determining what effects the 1964 flood had on the lower Deschutes.

Flow Regulation by PGE and Spawning Habitat Downstream

Water storage by the PGE hydroelectric complex during the 1964 flood prevented the considerable damage to downstream spawning habitat which was caused by that event from being even more severe. Our attributing of this beneficial, albeit unanticipated, effect to the PGE complex is based upon the following points:

- Extreme flood events can and do damage or destroy spawning habitat in rivers. The 1964 flood severely damaged spawning habitat in a number of rivers in Oregon, including the lower Deschutes (Al Lichens, ODFW-retired, Estacada, OR, pers. comm.).

- Round Butte Reservoir captured the "spike" of the 1964 flood, limiting peak flows witnessed downstream during the event. Peak flows in Section I were held to approximately 35 percent (15,800 cfs/ 45,000 cfs) of what they would have been had the reservoir not stored most of the flood: flows at Moody, near the mouth of the Deschutes, were limited to 75,500 cfs, about 84 percent of the 90,000 cfs which would have been experienced there without the presence of Round Butte Reservoir.

- The effects of the 1964 flood on spawning habitat in Section I, immediately downstream of the PGE hydrocomplex, were relatively moderate in comparison to those on habitat in areas farther downriver (Warren Aney, ODFW, La Grande, OR, pers. comm.). Spawning habitat changes in Section I since the flood have apparently been greater than those experienced during the flood (Al Lichens, ODFW-retired, Estacada, OR, pers. comm.). These more recent changes probably reflect a lack of gravel recruitment from upstream areas combined with peak streamflows which have occasionally approached the volume of those experienced in 1964.

- Effects of the 1964 flood on spawning habitat in the Deschutes were most severe for areas well downstream of the PGE hydrocomplex (Al Lichens, ODFW-retired, Estacada, OR, pers. comm.). Many gravel bars in the lower study sections were blanketed by fine sediment, some were completely removed, and others were replaced by large, unsorted riverbed materials during the flood (Warren Aney, ODFW, La Grande, OR, pers. comm.). Spawning habitat in Section III, and particularly in

Section IV, was heavily damaged in 1964. Gradual changes in the condition of many spawning areas in sections II, III, and IV since the flood have generally not been as dramatic as those which took place during the event (Warren Aney, ODFW, La Grande, OR, pers. comm.).

- The relatively moderate effects of the 1964 flood on spawning habitat in Section I, as opposed to the other three study sections, was not due primarily to hydrologic characteristics of the Deschutes Basin. Peak streamflows in Section I since the 1964 flood have occassionally approached and nearly equalled the volume of those witnessed during the flood (15,100 cfs in 1982 versus 15,800 cfs in 1964). In contrast, flows recorded since 1964 at the Moody gage have not nearly approached those documented there during the 1964 flood. The greatest discharge at the Moody gage site since 1964 was 27,400 cfs recorded in 1982, only 36 percent of the peak flow observed in 1964.

Given Round Butte Reservoir's effect on flows in the lower Deschutes River during the 1964 flood and the relatively modest effect the reservoir appears to have had on the magnitude of peak flows downstream since 1964, we question whether the PGE complex has caused serious spawning habitat degradation in sections II, III, and IV. Spawning habitat in Section I has been affected by the PGE complex since the 1964 flood due apparently to a lack of gravel recruitment. The presence of the PGE dams likely prevented severe flood damage to prime spawning areas in Section I during the 1964 flood, but without the dams in place these areas would probably have recovered from that damage through natural processes.

Channel Geometry

River cross-sections for the Deschutes River at USGS transect sites near the Pelton and Moody gages are shown on transparent overlays in Appendix XVII. These two transect series show that the shape of the Deschutes River channel has changed over time at both locations.

The overlay series for the Deschutes River channel at the Pelton gage transect shows that the river deepened between 1960 and 1984. This suggests that the river is degrading its channel in Study Section I, probably as a result of restricted gravel recruitment and altered flow patterns.

The overlay series for the Moody gage transect shows another interesting pattern. Events between 1955 and 1960 and again between 1960 and 1965 caused substantial degradation of a large mid-channel gravel bar. Over the years since 1965, the gravel bar has been slowly agrading. This strongly suggests a continuous cyclical pattern of degradation during infrequent major flood events followed by aggradation with transported bed materials during interim years.

Contrasting the two gage transects, it can be seen that the downstream (Moody) transect can experience "recovery" after floods, erode its gravel bar, but that the upstream (Pelton) transect cannot because bed materials that might be delivered to it are intercepted by the PGE dams. This supports the observation of continuing gradual erosion of spawning habitat at the upper end of the study area (Study Section I).

ENHANCEMENT

A number of techniques have been successfully used by fishery managers on the Pacific coast to rehabilitate or enhance spawning habitat for salmon and steelhead. These techniques range from the construction of large, elaborately engineered and expensive spawning channels, to the placement of rock or log weirs in streams to create scour pools or catch gravel transported by high flows. Successful enhancement methods in one type of application may prove inadequate or inappropriate in another situation. It is important to design a given enhancement program based on the needs and constraints of the conditions present in a particular reach of river.

A review of the literature and discussions with fish biologists who have done habitat enhancement work indicates that the success of a project is dependent on careful site selection and sensible application of appropriate techniques. For streams with high flows, the magnitude of individual construction efforts and the possibilities of structural and functional failure are high. Consequently, most instream enhancement of spawning habitat has been done in streams considerably smaller than the Deschutes River. The following is a list of potential enhancement measures which were considered for the lower Deschutes River:

1. Enhancement or rehabilitation of abandoned spawning dunes.
2. Placement of gravel piles to produce spawning areas downstream.
3. Placing large boulders on spawning riffles to create hydraulic resting areas and cover for spawners.
4. Gravel bar scarification to improve conditions for spawning and food production.
5. Placement of enhancement structures near tributary mouths to accumulate gravels delivered to the mainstem Deschutes by peak tributary flows.
6. Establishment of artificial spawning riffles in the mainstem Deschutes.
7. Improvement of spawning habitat in tributaries.
8. Development of side channels to create new spawning habitat.
9. Use of a specialized gravel cleaner in areas where streambed concentrations of fine sediment are relatively high.

10. Request a change in reservoir operations by PGE and other agencies or organizations in the Deschutes Basin to minimize discharge patterns from Pelton Reregulation Dam which are asynchronous with respect to flows in lower river tributaries.
11. Delivery of greater flushing flows from a regulation facility (storage reservoir).

Enhancement Options

1. Spawning dune enhancement

Many of the spawning dunes constructed by fall chinook in Section I have become very pronounced and appear to have been abandoned by spawners. In certain cases the troughs in front of dunes contain only stream bed materials which fish are incapable of moving. Other dunes have become heavily armored on their crests, or have undesirable contours as a result of continued heavy spawning use by fall chinook. Based on discussions with members of the OSGC study team, it is apparent that many of the dunes in Study Section I are more pronounced now than they were in the 1960's. It is suspected that the controlled flows and limited gravel recruitment below Pelton Reregulation Dam may be responsible for the abandonment by fall chinook of certain spawning dunes.

The most pronounced spawning dunes in Section I could be used effectively as natural gravel retaining structures. Sorted and cleaned gravel of an appropriate size could be used to fill the troughs between a number of the dunes half to two-thirds full. If this enhancement strategy proved effective, similar supplementations could be made to other dunes.

The crests of some spawning dunes which appear to have been abandoned in Section I could also be modified. The concept of modifying dunes is not new. Gravel has been added to spawning dunes used by extremely large rainbow trout in the Lardeau River, British Columbia, where gravel recruitment is quite limited (H. Andrusak, DFO, British Columbia, pers. comm). The California Department of Fish & Game (CDFG) has modified the shape of a very large spawning dune at the Auditorium Riffle in the Feather River, California. (D.Painter, pers. comm.). Fall chinook use of the dune at

Auditorium Riffle had declined as a result of changes brought about by very heavy chinook spawning activity. Fish use of the dune increased dramatically when changes in the shape of the dune were reversed with a caterpillar tractor.

2. Gravel Piles

The deposition of large piles of screened gravel at specific points in the Deschutes River would increase spawning habitat. This technique would allow the placement of gravel in water too deep for heavy equipment use, and would require much less maintenance than a mechanically groomed spawning riffle. Gravel piles could also serve to retard the erosion of some islands in Study Section I.

Success of this technique would be dependent on precise placement of the source materials. For this reason a hydrologist should evaluate each site before any gravel piles are created.

There are a number of places in each study section where gravel piles could be used to create spawning habitat or to protect islands. Gravel piles could be placed a short distance above the head of Jackson's Island (RM 99.9), just below Pelton Reregulation Dam, to enhance important salmon spawning habitat above that island and to halt erosion of the island itself. Jackson's Island should be protected in any case because critical spawning habitat in a side channel along its western edge will be seriously degraded if the river continues to erode the head of this island.

Because Jackson's Island is directly below Pelton Reregulation Dam, it would be important that any gravel deposited there is properly positioned. It might be necessary to protect the upstream face of any gravel deposited at that location with a few large boulders spaced in a way that allowed gradual erosion during high flow conditions and prevented the river from quickly removing the entire deposit. With this in mind, we would recommend that a prototype gravel pile be placed farther downstream in Section I before one is placed above Jackson's Island. Two candidate sites for such a prototype are the area just above Disney Island (RM = 98.9), on the-south side of the Deschutes and the area above the public boat ramp at Warm Springs (RM = 97.0).

3. Boulder Placements

Large angular boulders could be used in the Deschutes to alter flow patterns over a few mid-channel gravel bars which are presently under-utilized by chinook spawners. These boulders would dig scour holes or create deposition areas, depending on boulder size relative to high flow stream stage, and generally make the available spawning habitat more heterogeneous. This would tend to provide desirable hydraulic conditions over the bar for a wider range of river flows.

A diamond shaped orientation of four boulders is often placed in streams to improve fish habitat. This same general arrangement, with the proper size and spacing of boulders determined by an experienced hydrologist, could be utilized on the Deschutes. A good site for implementing this enhancement technique is located near the upper end of Study Section II, at bar 2065 (RM 95). Vehicular access to this gravel bar is along a dirt road on'the east bank of the river.

If other bars were selected for boulder placement, it would be important that they be located near a source of large boulders or near a road by which boulders can be delivered to the site. Helicopter transport of boulders from remote sites would probably be prohibitively expensive.

4. Gravel Bar Scarification

A number of gravel bars on the lower Deschutes are compacted and are presently thought to be unused by spawning fish. A few of these bars are known to have been used by chinook spawners in the 1960's. Some of them are still occasionally used by spawning chinook.

Some compacted bars could be made suitable again for chinook spawning by breaking up their surfaces with ripper teeth mounted on a large caterpillar tractor. The effective life of this enhancement measure would depend on the rate at which bars would become compacted again. If a particular bar is compacted because of prevailing river conditions, scarification would improve spawning habitat only temporarily unless continued fish use maintains gravel quality. However, if a bar is compacted as a result of persistent effects of the 1964 flood, and the river or spawning fish have been unable to significantly loosen the gravel-fines matrix, scarification could provide long-term enhancement.

Among the opportunities for this type of enhancement activity are gravel bars at Fall Canyon (RM 10.2) in Section IV, and at Windy Flat (RM 65.2) in Section III. The Fall Canyon site is on the west side of the Deschutes and would be extremely difficult to reach with heavy equipment. Vehicular access to the Windy Flat site is via a dirt road which heads south from of Maupin along the east bank of the river. This is one of the few gravel bars in sections III or IV where the river bank slopes gently enough toward the river to allow relatively simple tractor access.

The Windy Flat gravel bar would be a good choice for a first effort at bar scarification. It is shallow enough to work on with heavy equipment and was sampled during the course of the study reported here. The fact that it has been studied would allow some interesting monitoring once conditions on the bar have been enhanced.

Scarifying gravel bars would stir up large quantities of fine sediment and increase water turbidity. For this reason it would be important to schedule any bar scarifying activity to minimize the effect that this would have on areas downstream. The Wild and Scenic River designation in effect on the Deschutes could make implementing this measure a difficult matter, in spite of its potential benefit.

5. Place Enhancement Structures near Tributary Mouths.

Enhancement techniques used to sort and retain (stabilize) gravel have been tested primarily in small streams rather than in large rivers like the Deschutes. Structures like gabions (Anderson and Cameron 1980; House and Boehne in press); boulder berms (Everest and Sedell 1984; and Heller 1984) and log sills (Green 1984; Wiley 1984) have been used in smaller Oregon streams with a high rate of success, and would be applicable to side channels in the Deschutes (see below). However, techniques for trapping gravel in large rivers are not well developed. Due to the hydraulics of large rivers, any attempt at collecting gravel with structures which span the channel would probably be unsuccessful.

In larger streams, spawning habitat along channel margins has been improved through the use of groynes or jettys extending into the channel. These structures provide eddies or slack water zones which allows gravel to be deposited downstream. This technique of creating small gravel bars along channel margins in larger stream is applicable to rivers such as the Deschutes.

The USDA Forest Service has used offset deflecters in Hurdy Gurdy Creek California to produce up to 20-fold increases in spawning gravel deposition and retention. Hurdy Gurdy Creek is approximately 100 ft in width with peak flows of 7500 - 8500 cfs (Kerry Overton, USFS, Eureka, California, pers. comm.).

Although an offset pattern of opposing groynes would have only a marginal chance of success in a river as large as the Deschutes, placing groynes or clusters of very large boulders a short distance above or below the mouths of certain Deschutes River tributaries, particularly in

Section IV, has the potential of increasing available spawning habitat. The increase would be realized when a gravel bar was formed immediately downstream from the tributary which delivers bedload to the Deschutes. This type of gravel bar does not presently form below the mouths of many lower Deschutes tributaries because the Deschutes River tends to remove whatever gravel they deliver to the mainstem. Natural structures which provide hydraulic characteristics along the stream margin which sort and deposit spawning gravel are uncommon in the lower Deschutes.

Belief in the potential success of this action is based upon observations made during this study. One of the few deposits of gravel presently utilized by steelhead in Section IV has developed because a rocky point protects the mouth of an intermittent creek from excessive scour during high flow.

Accurate placement of enhancement structures to be used to protect tributary deposits of gravel from being scoured by mainstem flows will be essential to the success of this measure. For this reason it is important that an experienced hydrologist assist in this process. Some adjustments in the sizing or placement gravel catchment structures the deposition agent may be necessary after initial work has been completed.

6. Create Spawning Riffles

One of the oldest methods used to increase the amount of spawning area is the addition of spawning gravel. This technique yields increases in the amount of gravel available for spawning fish, but the deposits are often unstable and short-lived. This can be particularly true for a large river which is capable of moving even large spawning gravel at high flows.

For example, the California Department of Fish & Game placed 6600 cubic meters of gravel in a riffle on the Sacramento River, only to have the gravel removed by scouring flows (K. Buer, pers. comm.). In contrast, gravel placement in the Feather River, below Lake Oroville proved to be a very effective way to create new spawning habitat. In this situation, a swift run was effectively transformed into a very heavily used spawning area for fall chinook, although the area will require periodic supplementations of gravel.

Other problems can arise when attempting to create artificial spawning areas in large streams. Long, carefully groomed and highly uniform gravel bars were constructed in the Trinity River in Northern California to provide suitable spawning conditions for chinook. The fish used only the upper and lower ends of these riffles, ignoring most of the habitat in the middle. Apparently holding areas and desirable boundary layer conditions were absent except at the heads and tails of these riffles. Similar observations were made at the Carmen Smith spawning channel near Eugene, Oregon (Lou Fredd, ODFW, Portland, OR, pers. comm.). Such events demonstrate the necessity for heterogeneous hydraulic conditions on and near spawning areas.

7. Tributary Spawning Habitat Enhancement

Some Deschutes River steelhead use tributary streams for spawning. From a stream system perspective, if spawning habitat is limiting populations of steelhead in the

Deschutes Basin, enhancement in tributary streams should accompany similar efforts in the mainstem. Techniques for this type of enhancement have been reviewed and described extensively elsewhere (Baker and Hall 1982; Reeves and Roelofs 1983; Bottom, et. al. 1985; many others) and are the subject of a large number of activities presently being implemented by the Bonneville Power Administration as measures in the Northwest Power Planning Council's Fish and Wildlife Plan.

Abundant opportunities for increasing the amount of steelhead spawning habitat undoubtedly exist in several of the perennial tributaries of the Deschutes River. These opportunities could be inventoried, evaluated and implemented if practical and promising.

8. Side Channels

Two types of side channels provide opportunities for spawning habitat enhancement work. One is a small side channel with limited gravel deposits and year-round flow. Such channels can be enhanced by placing gravel retention structures in them which will alter flow patterns and result in the accumulation of spawning gravels. In some cases it can be necessary to place screened gravel in front of the structures because natural gravel delivery to the enhancement site can proceed at a very slow rate.

Ephemeral side channels of large rivers can often provide excellent cost-effective opportunities for enhancing spawning habitat. This is accomplished by carefully modifying the upstream ends of these channels and diverting water into them from the main river channel to create habitat where none existed before. The benefits of this type of activity are two-fold, since it can increase both spawning and rearing habitat.

Enhancement of ephemeral side channels requires careful planning and might involve placement of an adjustable flow-controlling structure at the upstream end. In addition, it is sometimes desirable to restructure the hydraulic geometry of the channel with heavy equipment and to modify the lower end of the channel to improve spawner access from the main river.

Instream structures like boulder berms or weirs can be placed in ephemeral sidechannels at regular intervals to control water velocities, create a desirable pool-riffle sequence, or retain gravel for use by spawners. Gravel can be added to the channel or allowed to accumulate naturally, depending on the anticipated rate of gravel movement through the channel. This concept of enhancing ephemeral channels forms the basis of recommendations which have been made to the California Department of Fish & Game on ways to increase spawning habitat in the Klamath River, California (Buer, pers. comm.). The way in which an ephemeral side channel could be developed as a spawning area has been described in detail be the California Department of Water Resources (1981).

Unlike many rivers, the Deschutes is generally lacking in this type of enhancement opportunity. One opportunity for this activity, just downstream of Harris Canyon (RM 12.0), has been identified and utilized by the ODFW. There are a number of reasons for the lack of these opportunities on the Deschutes, including a relatively steep river gradient and the fact that lateral movement of the river is restricted along much of its length by steep, often rocky banks. The 1964 flood may also have obliterated old meander and flood relief channels which had existed prior to that event.

9. Gravel Cleaning Machines

A number of spawning gravel cleaners have been developed and tested. The cleaners are designed to remove fine sediment from gravel and thus increase salmonid egg and alevin survival. High costs associated with operating the machines and a frequent need to reclean the treated gravel generally limit the use of available cleaning devices to heavily used spawning areas and man-made spawning channels.

Machines still being developed (e.g. Mih, 1978) which utilize hydraulic jets have been shown capable of removing fine sediment from relatively homogeneous gravel deposits (Allen *et al*., 1980). However, these hydraulic gravel cleaners are unable to clean the coarse or poorly sorted gravel typically found in many large rivers. Another gravel cleaner, which employs a vibrating, screen-backed digging bucket mounted on a Gradeall tractor, has been used to improve gravel quality in a British Columbia River (Andrew, 1976; 1981; pers. comm.).

There are a number of considerations which make the use of a gravel cleaning machine in the Deschutes advisable. The machines are very expensive to build and use, and provide benefits which will be short lived if fine sediments are frequently delivered to the enhancement site. Also, fish sometimes do not show a strong preference for the cleaned gravel. Sediment released from the streambed during a major gravel cleaning operation can have adverse effects on water quality, and aquatic life downstream.

10. Change Hydrocomplex Operations to Eliminate or Reduce Asynchronous Discharge

The issue of asynchronous discharge from the Pelton/Round Butte hydrocomplex and the implications for spawning habitat quantity, quality and distribution were discussed in the Flows portion of the Results and Discussion section of this report. Asynchronous flows could be mitigated or avoided by altering hydrocomplex operations or the storage patterns of reservoirs farther upstream to match the timing of high flow releases from the PGE complex more closely with those of major tributaries downstream. This process would be significantly enhanced by coordination with operators of upper basin reservoir to provide optimum streamflow characteristics when necessary. Implementation of this enhancement strategy would require coordination agreements among ODFW, PGE, and operators of upper basin reservoirs.

11. Flushing Flows

The concept of releasing flushing discharges from the Pelton/Round Butte hydrocomplex was previously discussed. As mentioned in that discussion, flushing flows were recommended in the 1960's by the OSGC for the purpose of maintaining spawning gravel quality by scouring fine sediment away. The implication of increased flushing flows under present conditions in the lower Deschutes were also discussed. If increased flushing flows are needed to clean presently compacted gravels or to reverse encroachment of vegetation, some means must be devised to protect important spawning areas in Section I and portions of Section II from excessive degradation (erosion). This is a very important consideration because a significant proportion of spawning habitat in the upper study sections, especially that for steelhead, would be placed at risk if flushing flows sufficient to scour compacted gravels and encroaching vegetation were implemented.

CONCLUSIONS/RECOMMENDATIONS

Several conclusions have been reached during this study. These conclusions are:

Snawning Gravel Area

- The 1964 flood had a profound effect on the quantity, distribution, and probably quality of spawning gravel in the Deschutes.

- The magnitude of the 1964 flood and its consequences obscured certain changes which might otherwise have occurred or been attributable to the hydrocomplex.

- The 1964 flood would probably have caused significantly more damage to critical spawning habitat in Section I, and possibly in the other three study sections, without the PGE hydrocomplex in place.

- There has been a reduction in the quantity of spawning gravel present in Study Section I since the mid-1960's, as a result of restricted gravel recruitment from areas upstream of the PGE hydrocomplex. The loss of this habitat may occur at an accelerated rate as islands in the Section are lost to erosion.

o Changes in spawning habitat within Section I since the 1964 flood have apparently been greater than those caused by the flood.

o The amount of spawning gravel present in sections II, III and IV declined substantially during the 1964 flood.

o Changes in the amount of spawning gravel present in sections II, III and IV since the flood cannot be defined quantitatively using available data. However, it is suspected that there have been changes in the quantity of spawning gravel present these sections since the flood.

o The amount of spawning gravel suitable for summer steelhead (and/or resident rainbow) trout and fall chinook salmon use in the lower Deschutes generally declines in a downstream direction.

- There is substantially more chinook spawning habitat in the lower river (Section IV) than previously thought.

- There appear to be spawning areas for chinook salmon, particularly in deeper areas of the lower Deschutes, which have never been identified. This habitat tends to be found in the center of the river channel and is difficult to identify. A number of these areas may be visible only from altitudes notably higher than those flown during standard redd surveys.

- There are some signs of encroachment by aquatic, emergent and riparian vegetation on spawning areas in the river, particularly in sections I and II.

<u>Gravel Permeability</u>

- The standpipe procedure used to measure gravel permeability during this study and the OSGC study produces extremely variable results. It is therefore not recommended for use in situations where statistical sensitivity is important.

- Because of extreme variability in all data sets, both those obtained during this study and those of the OSGC, no conclusion can be reached regarding gravel permeability changes which may have taken place in the Deschutes since the mid-1960's.

- Gravel permeabilities recorded during this study were the highest in Section I and lowest in Section IV.

Gravel Composition

- Present baseline conditions of gravel quality in the lower Deschutes were documented using a freeze-core methodology.

- Mean Fredle indices calculated for the gravel depth most likely to limit rates of survival for salmonid embyros ranged between 5.61 and 14.03 in chinook spawning areas and from 2.63 to 9.78 in steelhead spawning areas. These values suggest that gravel quality is good at most spawning areas sampled.

- Better gravel quality was found in spawning areas below White River (based on Fredle indices) than has previously been thought present in that reach of the river.

Spawner Use

- Fall chinook in the Deschutes River are capable of spawning successfully in gravel which most fish biologists would considered marginal or unusable.

- Fall chinook in the Deschutes River are capable of strongly influencing the quality of their spawning habitat.

- Fall chinook spawning in the Deschutes is often associated with spawning dunes, particularly in Section I.

- Many spawning dunes, especially some of those in Section I, appear to have been abandoned be fall chinook.

- Most steelhead/resident trout spawn in the upper portion of the study area (sections I and II) as they did in the mid-1960's.

- The proportion of steelhead/resident trout spawning in the river which occurs in Study Section I has apparently declined since the mid-1960's, perhaps reflecting a reduction in spawning area or a reduced local population of resident trout.

- Nearly all of the suitable steelhead/resident trout spawning habitat present in the upper three study sections (I, II and III) receives heavy use by spawning fish.

- The distribution of steelhead/resident trout spawning activity in the Deschutes appears more closely related to the distribution of suitable gravel than to differences in spawning gravel quality as reflected by Fredle indices.

Flows

- Mainstem flows below the Pelton/Round Butte hydrocomplex are often asynchronous with respect to tributary flows.

- Asynchronous flows could lead to undesirable patterns of sediment deposition.

- Peak flows in the lower Deschutes since completion of the PGE hydrocomplex have not been appreciably lower than those experienced prior to completion.

- Not all recent changes in the flow patterns of the lower Deschutes River are attributable to the PGE hydrocomplex. Significant changes in flow patterns have been observed in a major unregulated tributary stream. These changes resemble those in the mainstem and again suggest that factors other than the PGE hydrocomplex are playing a role in observed changes in Deschutes River hydrology.

- Some changes in lower river flow patterns can be attributed to upper basin impoundments. Seasonal water storage in reservoirs upstream of the PGE complex is typically an order of magnitude greater than that in Round Butte Reservoir.

- Land use practices and/or meteorological conditions may be responsible for altered flow patterns.

- Timing of peak flows in the lower mainstem has shifted from spring towards winter.

- Part of the seasonal shift in mainstem flow patterns is due to the PGE hydrocomplex and part of it is not.

Enhancement

- There are a number of viable opportunities for enhancing the spawning habitat of Deschutes River salmonids, both in the mainstem and probably in a number of tributary streams.

- There are needs and opportunities to acquire additional information relating to anadromous and resident salmonid spawning habitat in the lower Deschutes.

Based on these conclusions, and as a result of a consideration of reasonable habitat enhancement techniques and opportunities identified during this study, several specific habitat enhancement or mitigation measures could be implemented. It is recommended that these measures be implemented only to the extent that it is independently concluded that spawning habitat is limiting populations of naturally reproducing anadromous or resident salmonid populations in the Deschutes River.

If spawning habitat enhancement is warranted, a three phase program of enhancing spawning gravel in the river should be undertaken. The program should begin with the implementation of prototype spawning habitat enhancement methods in the river. Next, the effectiveness of these initial enhancement efforts should be monitored for a period of time to determine how effective they are in terms of both physical habitat changes and fish utilization. Prototype methods should be abandoned or modified and re-tested if they are unsuccessful in achieving the desired results. Finally, based on experiences with the prototype efforts and an economic analysis of expected benefits, a major gravel enhancement effort would be undertaken.

Since the naturally reproducing fall chinook salmon and steelhead trout in the Deschutes have distinctly different spawning requirements and life histories, it is possible that production of one species may be limited by available spawning habitat while that of the other is not. For this reason it may be advisable to select enhancement strategies which are designed primarily to increase or improve spawning habitat for one of the two species. In many cases the same general enhancement method can be used for both species with only a slight change in the sizing and placement of materials used.

Should it be decided that a major program to enhance spawning habitat in the Deschutes is called for, the following actions are recommended for the first phase of that program:

- Add 1 to 4 inch diameter screened gravel to the troughs between dunes at the Guard Rail (RM 98.5) and Valve (RM 99.6) stations. Gravel should be added until the troughs are half to two-thirds full.

- Deposit gravel piles at the head of Jackson's Island (with some armoring), above Disney Island and above the public boat ramp at Warm Springs (RM 97.2).

- Place large boulders on bar 2065 (RM 96) to produce more heterogeneous hydraulic conditions and add to holding areas for adult fish. An additional site for this technique is bar 2165 (RM 94.1).

- Scarify the surfaces of gravel bars at Fall Canyon (RM 10.2) and Windy Flat (RM 65.2).

- Place gravel retainment structures near the mouths of Rattlesnake Canyon (RM30.3), Oak Brook (RM 36.1), Buck Hollow Creek, Bakeoven Creek (RM 51.4), and Jones Canyon (RM 34.3).

- Develop spawning habitat in the side channels at RM 58.8 (right bank) and at the public boat ramp upstream of the Warm Springs Bridge (RM 97.2). Three or four other side channels could be enhanced for spawning, some through addition of gravel alone and some through addition of gravel and gravel retention structures.

  The Oregon Department of Fish and Wildlife has recently developed an ephemeral side channel at Sharp's Island (RM 12). No other ephemeral channels should be developed until this effort has been evaluated.

- Survey Nena, Oak Brook, Buck Hollow, Bakeoven, Shitike Eagle and Wapinitia creeks for opportunities to enhance spawning habitat. Enhance habitat in those which offer significant benefit potential.

- Develop precise synchrony criteria for discharge at the Pelton gage site to optimize high flow characteristics in the lower river.

- Do not create artificial spawning riffles, use gravel cleaning machines, or seek increased flushing flows to improve spawning habitat in the Deschutes.

Additional Information Needs

During the course of this study, a number of needs for additional information pertaining to anadromous and resident populations of salmonids in the Deschutes River and their spawning habitat became evident. It is recommended that efforts be undertaken to acquire this information through additional studies or other means. These include:

- A detailed aerial survey of fall chinook spawning activity in the lower Deschutes River should be conducted to determine which gravel bars in the river are presently used by spawners. Information obtained from such a survey could then be compared to the results of surveys conducted by the OSGC in the 1960's to determine how spawner use patterns have changed over time. This type of comparison could be greatly enhanced through the participation of a biologist who was involved in the surveys made by the OSGC (e.g. Al

Lichens). Data collected during the aerial survey would also serve as a baseline on present conditions to which the findings of periodic (e.g. 5 year) follow-up surveys could be compared.

- If a detailed survey of chinook spawning is undertaken, attention could be given to the locations of spawning sites selected by fall chinook in each spawning area. Information on the distribution of chinook redds within spawning areas will help to identify fish responses to habitat changes. For example, such information could be used to determine whether or not certain spawning dunes or other key historical spawning sites in the river are presently being used by fish.

- Each fall, the ODFW and PGE conduct redd counts in selected index reaches of the lower Deschutes from a helicopter to monitor fall chinook spawning activity. At the present time the total number of redds counted within each index reach is recorded without regard to where in each reach they are located. The number of redds counted in distinct spawning areas within each index reach should be recorded separately during future redd counts. Counts made in this fashion over a period of time would identify shifts in spawner use patterns which would not otherwise be evident.

- Observations made during this study suggest that there are major fall chinook spawning areas in deep water that can only be viewed from a greater altitude than that from which redd counts are presently made on the Deschutes. These important spawning areas were previously unknown to biologists. An effort should be made to determine how many of these areas exist, where they are located, how large they are and how extensively they are used by fish. If these areas comprise a significant portion of total available spawning area for chinook salmon in the Deschutes River, they should be incorporated into annual redd counts. Subsequent redd counts could be indexed to records from previous years by noting the ratios of counts from new and old areas and counts from high and low altitude passes over a few seasons. Previous years' records could then be corrected to more accurately reflect historical spawner distribution.

- Efforts should be made to identify how much of the steelhead production in the Deschutes system is attributable to spawning and rearing in tributary streams. Unlike fall chinook, which are essentially restricted to the mainstem lower Deschutes, steelhead spawn in tributaries like the Warm Springs River and Trout Creek. It is unclear what proportion of the summer steelhead run is composed of tributary spawners because data on spawning activity in most of the tributaries is sparse.

- Naturally reproducing anadromous salmonids are no longer produced in the Deschutes drainage above the PGE hydrocomplex because no effective means of passing smolts downstream around the three dams was ever developed. The reintroduction of viable salmon and steelhead populations to the upper drainage would probably be possible if the problem of downstream passage could be solved. For this reason, the development of an effective system for passing smolts downstream around the PGE dams should be encouraged. Such a system would greatly increase the amount of habitat available for the production of wild salmon and steelhead in the Deschutes drainage. The downstream passage problem presently appears to be related to the lack of a flow net in surface waters aggravated by certain meteorological conditions. A hydrological and meterological (wind) model of the Billy Chinook Lake would help clarify this question.

o The deposits of spawning gravel mapped on air photo overlays during this study should be reexamined at some time in the future to determine whether any changes have taken place in the quantity and distribution of spawning gravel in the Deschutes. The set of 1:2000 scale infared aerial photographs of the lower Deschutes used during this study were taken in 1982 and provide excellent documentation of river channel characteristics (e.g. river width, location and size of islands, etc.) which may change in response to modified flows. If at some time in the future it is suspected that conditions in the Deschutes have deteriorated, a set of similar photos should be generated and compared to those taken in 1982.

o An effort should be made to determine how much and how frequently gravel movement takes place at selected sites on the lower Deschutes. If gravel retaining structures are placed in the river as part of a gravel enhancement program, the rate at which they trap gravel will help in this determination.

- The freeze-core gravel sampling done during this study should be repeated periodically to monitor gravel quality (e.g. every 5-7 years) in the Deschutes. Freeze core sampling could also be conducted during a year in which streamflow conditions in the Deschutes are thought likely to have had an adverse effect on gravel quality (i.e. years with low average spring streamflows for the upper basin and pronounced asynchrony between releases from the Pelton reregulation facility and tributary flows) to determine whether gravel quality problems have developed. The results of such sampling would indicate where in the river future gravel quality problems are most likely to develop.

- Without natural gravel recruitment from areas upstream of the Pelton Reregulating Dam, tributaries of the lower Deschutes play a critical role in supplying gravel necessary for the long-term maintenance of spawning areas in the river. The gravel budget of the

Deschutes is poorly understood at the present time. However, it is important to consider the potential for reductions in salmon and steelhead spawning habitat when planning activities that might reduce the rates at which tributaries deliver gravel to the mainstem. Some effort should be made to determine the gravel budget needs of the Deschutes River in order to preserve existing spawning habitat.

o Resident rainbow trout in the Deschutes River spawn in many areas utilized by spawning summer steelhead. Based on observations made during trout redd counts in 1984, this common use of spawning areas can lead to superimposition of resident trout redds on steelhead redds. The effect of this superimposition on steelhead egg survival in the river is unknown and is worthy of investigation.

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